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MAN'S IMITATION OF NATURE IN PURIFICATION OF WATER.

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[*Read Sept. 15, 1898.*]

As engineers, you are asked to suggest a means of supplying a municipality with a suitable water supply. This means to the engineer a potable water and one which at the same time is adaptable to mechanical uses, for the production of steam and for domestic purposes.

In looking over the immediate vicinity of the locality to be supplied, it is seldom that a supply which is satisfactory in quantity and quality is available. If the water is exceptionally pure the quantity is sure to be limited, and if in considerable quantity it is apt to be so far removed as to make it impracticable to introduce the supply when the question of expense is considered. When it is necessary to depend upon ponds, lakes or rivers the probabilities are that the supply is already receiving contaminations or the watershed is liable to invasion from human habitation and will at some future time become liable to contamination.

The question then arises as to how far we are justified in recommending a supply which is polluted or liable to pollution, and at the same time we may ask whether there is really any such a thing as a pure water supply obtainable.

Of this fact, that there are supplies which are naturally pure is shown by the analysis of the water supplies of many municipalities. These waters taken from their original source are delivered to the consumer without artificial interference of any kind, and are yet satisfactory in quality and quantity.

There are waters therefore which are purified by nature, for in their original state as supplied by the natural rain they are contaminated by the air through which they pass and by the surface contaminations which are gathered to the water from the surface of the earth where the rain has fallen. Yet this same water comes to us from subterranean passages clear and pure, bacteriologically and chemically. What was once a muddy, highly colored water loaded with organic and mineral matters in suspension has been deprived of those ingredients and the water comes to us white in color, palatable to the taste and free from excess of organic matter though highly charged with mineral matter in solution.

It is desirable that we become perfectly familiar with nature's methods in effecting these conditions, for we are now daily called upon to produce these changes artificially, rapidly and upon a large scale. In so doing there has been no device presented or method or process which is not an imitation of nature, unless it be the process of boiling the supply and as this water is devoid of taste from loss of aeration it cannot be called a potable water.

The purest waters obtainable in nature are derived from so-called natural springs or from artesan or driven wells, which are natural springs tapped by man.

Our natural inquiry is at once directed to the conditions to which this water is subjected—this water which was once impure and now comes from the depths of the earth free from all contaminations. We are at once informed by those who have given this matter much thought and investigation that this water has been percolated or filtered through innumerable layers, of varying densities of earth and that the many particles of organic matter held in supension have become caught in the meshes or interstices of the media through which it is passed leaving the water free from suspended matters. Natural springs uncontaminated by matters received from the surface flow, and artesian and driven wells taking water from below an inpervious strata should be bacteriologically pure to the extent of less than fifty organisms per cubic centimetre, and in

many cases it is possible that even such numbers may be derived from pump packings or from effluent pipes. The writer has examined several waters which were practically sterile taken from these sources. When a contaminated river water, or a muddy river or lake water is the only source available for a city supply, the engineer avails himself of nature's methods and endeavors to imitate by constructing sand beds of fine sand, which we are told, as the results of actual experience in Europe and as the result of long and careful experimentation at Lawrence, should be of a certain depth, and the sand of a certain degree of fineness and through which the water may be allowed to pass. But in our attempts to supply the large quantity of water required for a city supply we are tempted to permit the water to pass through the filter in such large quantities, or rather at such a rapid rate, that the effluent waste is not as clear and pure as desired and does not resemble nature's product.

When we inquire from our experts at the experiment station the reason for this we are informed that the water which has been filtered by nature has been drawn from a large area and that the rate of filtration has been extremely slow, and that in many instances it has passed to great depths. This latter requisite however is not essential as is shown by examination of a filter bed, the most efficient filtration being effected by the first few inches of sand on the surface, the substrata or coarser sand serving merely as a supporting mass or foundation for the finer filtering media.

Until recently we were also advised that the mass of organic matter which is caught on the surface of the filter bed, forming a thin scum or slimy stratum, served solely as a filtering media and without that layer successful filtration could not be accomplished. It has now been determined however that after filtration has been commenced and the layer once formed that the scum may be removed, and if the superstrata of sand is not disturbed that quite effectual filtration, though not complete, may be accomplished. We were told that if a fracture or lack of continuity of this slimy surface occurred that the impure water would find its way through without purification. This still holds true, for in this case there is a break or channel passing through the upper layer of sand as well as through the slimy layer.

Equipped with this data the engineer attempts to judge of the depth of sand necessary for a water of average impurity. He esti-

mates the rate of filtration possible through this material and then determines the area of surface which will be required for filtering the enormous amount of water required for a given municipality. This naturally leads to the consideration of cost, for unless the large acreage required be available at some point removed from the city where land is of slight expense, the cost for the land becomes a serious obstacle. Even after the land becomes available the cost of a sand of a requisite degree of fineness and sharpness must be considered since it must usually be obtained from a distance and the transportation adds materially to the cost. If, as is the case of Atlanta and other cities, where the water must be raised to a considerable height in order to reach the filter bed, the cost is proportionally increased. The city is fortunate therefore which can avail itself of the natural fall of the supply to flood the beds without pumping. This is demonstrated in the filter plant which is in use at Denver. Here the water flows from the mountains directly into the filters which are in this case semi-mechanical filters, that is, are tanks of sand which are cleaned by agitation of the sand by means of revolving forks and return flow, but in which no alum is used.

Another means which nature has provided and which serves in many cases, as in the supplementary plant in Denver, is the natural formation of filter galleries and which is imitated by man in the use of natural soil found on the banks or beneath the beds of streams where the natural earth formation is of the proper porosity. This form of filtration is, however, usually so rapid that little more than the gross suspended matter is removed, and as is the case with all filtration, the less the amount of organic or suspended matter present in the water, the more difficult is perfect filtration. Reversely, the greater amount of suspended matter, the more successful the filtration. This naturally occurs as the result of the organic matter becoming caught in the interstices of the filtering media, and as we previously were led to believe the organic matter present produces more quickly an effective filtering scum or surface layer upon the supporting sand.

In examining the purest waters derived from artesian wells it has been found that they contained large quantities of mineral salts. These we are told have been taken up from the earth and from the soluble elements through which the water has percolated. This advances the suggestion that nature has possibly utilized these salts in

a measure to assist in the purification, and leads us to consider the results if we should add to our unpurified water, salts of a similiar character, or other materials, which would produce an effect of some kind upon the suspended matters in our impure waters. Therefore alum, iron and other chemicals have been suggested from time to time, but alum, from its availability and from its more successful action upon suspended organic matters in water, has been adopted at the present time as being the most desirable coagulant or precipitant. We have therefore introduced to our attention the process of mechanical filtration, that is, the utilization of a precipitant in addition to the use of mechanical devises which aid in the cleansing of the filtering media which constitutes the bed, and to which system the name of American filtration has been applied.

This method we have placed before us by the various patented systems which have the same common principle of a coagulant and agitation of a filter bed. We are familiar with these systems first known as the Hyatt filter, and now known under the names of the Morison-Jewell filter, the New York filter, the Warren filter, the Western and the National, and which have now been amalgamated under the firm name of the New York Filter Company.

These practically differ from each other only in the method of applying the precipitant and in the use of certain accurate mechanical devices for introducing the precipitant and latterly in the treatment of the applied water before being introduced into the filter proper. One other difference has up to the present time existed, and that has been a great obstacle to the introduction of mechanical filtration, and that is the litigation which has attended the installation of these plants.

As we are all aware, much valuable time, money and loss of valuable contracts have occurred as the result of the many injunctions and threats of the New York Filter Company against the Morison-Jewell Company; but after the installation of the Niagara plant and the Lorraine plant by the Morison-Jewell Company, and the many injunctions against them in favor of the New York company, the matter has now come to an end, and it is safe to say that under new administration it may be possible for either or both companies to introduce their processes to a city without being obstructed on the grounds of suits for infringements.

The city of Providence having appropriated the sum of $180,000

for a filtration plant of 15,000,000 gallons capacity, withheld the signing of the contract at the last moment owing to fears of litigation. The city of Albany was strongly influenced in contracting for a natural filtration plant, to avoid litigation.

As has been stated, the chemicals used in this method are similarly used by each company, but they have until recently been applied in entirely different ways. The method adopted by the New York Filter Company and as is in use at the filtration plant at Atlanta, Georgia, and other plants, is to place an indefinite bulk of crude alum in a receiver through which a small by-pass of water may flow, and which again enters the applied water before reaching the filter. It requires but little reflection to satisfy oneself that the water passing about the large bulk of alum soon after the first charge in the receiver must necessarily be a saturated solution and may be supplying more grains per gallon of water than is necessary to produce the change or precipitation of the organic matter present, and thus make it possible to have a quantity of alum in the mains. Likewise, when the alum in the receiver has been reduced to a minimum, from its constant contact with the passing water, the remaining amount of alum cannot give up the necessary amount of grains per gallon to successfully purify the water. This method of applying the precipitant is therefore unreliable. The use of this method of filtration is not in all cases for the purpose of removing suspended matters which are visible to the eye and which, while harmless, are yet unsightly or odorous. It may be used in comparatively clear waters which have a known contamination from excreta from man. Into the supply pipes no water should pass without being treated with the proper amount of precipitant, for as soon as the alum is reduced to below the normal requirement, the water passing through becomes a possible source of danger. To the mind of the engineer or ordinary mechanic it would seem absurd that this clumsy method should continue in practice or be presented to a municipality for use. The suggestion would at once present itself: why not apply the desired amount in strength and quantity in proportion to the amount of organic matter present and in proportion to the amount of water passing through the filter, as we would naturally do when we desire any other exact chemical or mechanical mixture?

The Morison-Jewell Filter Company as with other companies which have been shown to be infringers upon the original method,

adopted appliances which would accomplish this. A solution of a standard strength of alum was mixed, the standard depending upon the amount of organic matter present and determined by experiment before filtration. This standard solution is then ejected into the applied water in quantity proportioned to the amount of water passing through the mains. This latter application is brought about by different devices by the different companies, and any preference would exist therefore for the best mechanical device which is used for injecting or mixing the applied solution.

But in the use of this form of coagulant we improve upon nature inasmuch as the amount of alum applied is in proportion to the demand and *no other salts* are added. In nature the amounts found are in excess of the need. One of the objections which has been raised to the use of the mechanical filtration is the alleged possibility of a dangerous quantity of alum finding its way into the filters and being a cause of injury to the consumers. As a matter of fact during the experiments conducted at Providence in the process of mechanical filtration, there appeared less alum in the filtrate than in the applied water before it was treated, and in the experiments made at Lorraine, Louisville, Cincinnati and at Pittsburg, Pa., the same results hold true. No objection has yet been raised to the use of artesian and driven well supplies, although carrying large quantities of mineral matter. I have never heard of, nor am I able to obtain any evidence that the use of water filtered in this way has ever given rise to any disturbance of the alimentary tract, the portion of the human economy which would be the first involved if injury was to result. No reports are obtainable from Atlanta or other cities using alum as a precipitant, although by the manner in which the alum is applied there must at times be an excess of the applied chemical.

To ascertain the actual practical conditions which may result from a use of alum in this way the writer recently made inquiry of the health officers in cities having supplies of all the plants treated by the mechanical process, for the purpose of ascertaining if sickness of any kind had occurred from the continued use of alum as a precipitant. It was found that a great many of the cities were practically using the sand bed filtration with the rapid rate and the use of reversal current in washing, and the aid of iron rakes, but did not make use of alum, either because the effluent was suffi-

ciently clear or because there was no suspicion of sewage contamination, or in some cases where there was known pollution, for the sake of economy, the water companies were satisfied with simple clarification, and did not care whether there was a bacterial efficiency or not.

Of over one hundred cities which had mechanical plants, fifty-seven made reply. Of these only forty-five were filtering the water. Of these only forty found it necessary to use alum. Of these, seven used the alum intermittently while the rivers ran turbid, and thirty-three were using alum continuously. The amounts varied from one-tenth of a grain per gallon to seven grains per gallon. In three or four alum had been found in the filtrate. In not a single instance had any illness or symptons of intestinal disturbance been heard of in those using alum.

It is natural to raise this alarm about the addition of a chemical to the water, although wool washings, acids and bleaching chemicals may be in the supply continuously yet no complaint is made, but the addition of alum produces the alarm.

If any injury were to result; if any substantial objection could be raised, it would be made by the producers of steam as the result of incrustation of boilers, but all evidence obtainable from cities using such water, and from boiler insurance companies constantly making inspections, does not reveal any objectionable conditions.

Man, while using the same methods as nature, yet can, by the perfect control of the process in mechanical filtration, be enabled to filter larger quantities in a shorter space of time. The same is true when compared with the cruder method of sand bed filtration. By the use of sand filtration, a flow of 2,000,000 to 3,000,000 gallons per acre is possible, while with a properly adjusted mechanical filtration plant it is possible to reach as high as 125,000,000 gallons per acre per 24 hours.

Mechanical filtration has also an advantage possessed by nature which is not obtained by the sand filtration, namely, the power to continue the process during severe weather. If, however, it is necessary to use the sand bed filtration and to cover the beds, it necessitates an expenditure which makes the original cost too expensive.

From a bacteriological standpoint, one process is as perfect as the other. The mechanical filtration has the advantage however of being

quickly cleansed, and by mechanical labor instead of the intervention of human labor with its attendant slowness, danger of contamination from dirty shoes in walking over the bare beds, and also the possibility of seams or cracks forming in the surface of the bed, which can be corrected only by re-dressing the surface and which requires much time.

We are, as sanitary engineers prone to condemn the use of water from the ordinary dug well if it is possible to obtain a general public supply free from contamination. Our condemnation of the ordinary farm or house well is as natural as it is to condemn an untrapped sink, and both frequently without reason. It must not be forgotton that a large part of the population of this earth are obliged to depend upon water from dug wells as their only source of water supply for all purposes, and that the people using these wells are still alive and will probably continue so with the continued use of these wells. While it is good judgment and a safe one to condemn a well which is located in a populous district, yet we should be ready to give our reasons therefor. If a cesspool or a vault or a drain is located near a well there is sufficient suspicion, without examination of the water, that it may at any moment be contaminated. Yet no contamination exists in the majority of cases. If we will recall the conditions of the substrata of earth in making excavations in and about abandoned cesspools and privy vaults, we will recall that the discoloration of the earth does not extend beyond a few inches. We will remember that if the night soil man does not remove the entire contents of the cesspool, that he will return again, and that soon, since the cesspool is rapidly refilled owing to the accumulation of an impervious covering which has accumulated on the bottom of the cesspool. This is however, merely visual observation. Repeated experiments have shown that nature in this manner removes the contaminations which are found in the cesspool wastes and allows merely filtered water free from bacterial contaminations to pass through. This is demonstrated by the experiments conducted at Lawrence and at the various sewage filtration plants. The writer has observed as the result of filtration of sewage at the plant located at Pawtucket, R. I., that a sewage which contains 500,000 to 1,000-000 organisms to the cubic centimetre, shows in the effluent only 500 organisms, and it is the purpose of the plant always to avoid the accumulation of the sludge upon the surface which in a short

time so clogs the filter as to bring the percolation to a standstill, thus allowing, of course, surface filtration as occurs in nature. Should the filtration go on to the point of a slimy covering, the number of organisms in the effluent would materially decrease.

This same rule holds true in regard to the question upon which we are sometimes called to decide in reference to the dangerous proximity of a grave yard to a well or a proposed river supply. The writer has never seen at any exhumation the contamination of the soil beyond a few inches from the containing case and with the same conditions present as in a cesspool where the liquid contents are in greater quantity, hence the possibility of contamination from the remains buried in a cemetery are very remote. I am fully aware of opinions to the contrary, and while the idea may be repulsive, yet we should, as advisors of the public, give expression to our scientific judgment and not to our sentiment.

As the result of the biological experiments of Koch, Kitasato, Proschauer and Loeser, it has been demonstrated that not only are the organisms of contagious diseases destroyed in a short time in the presence of the toxines formed in the cadaver by the organisms of decomposition, but that the contamination of the soil extends to but a few inches from the retaining case or from the carcasses of animals. This was determined by examination of soil and waters in which animals had been buried, and also by examination of subsoil waters found in wells in cemeteries. It was always found that such waters were as good as any waters from wells in the same vicinity outside of the cemeteries. Of course when a cesspool or a grave has for its floor the surface of a rock or a hardpan over which is constantly flowing a subsoil river, this river may be readily contaminated and the contamination be carried to a neighboring supply. The greatest danger from the proximity of cesspools and wells is the liability of a break occurring at any time in the subsoil strata whereby a direct flow of the cesspool contents directly into the well is made possible.

In looking back in our text books not so many years ago, we find the statements that water running over a certain distance, usually cited as from seven to twelve miles, will purify itself, or rather become purified. It has also been stated, and generally believed, that the more agitation the water underwent, the more waterfalls over which the water ran, the sooner would the water be purified. But

at the present day, with our advanced knowledge and continued experimentation, we find, as we did with the all destroying theory of sewer gas, that we were preaching from a false prophet.

That the first statement is incorrect is shown, not alone by the continued examination, chemically and bacteriologically, of streams which have a known source and quantity of pollution, but is mournfully demonstrated by the epidemics which occur from time to time where a town affected by typhoid fever or cholera gives rise to an epidemic of the same kind and situated an indefinite number of miles below on the same river. Those who have watched the accumulation of fœcal matters at the mouth of a sewer, and in the winter time have seen these hardened masses discharged into a river and have seen them appear at distances further down the stream, know of the possibilities of contamination carried long distances.

While waterfalls and rapids serve to break up masses of this kind, as well as of organic matters of other kinds, and while it was supposed that the exposure to the sunlight and air brought about by this agitation would facilitate oxidization, we are now lead to believe that if this same water could pass along slowly, with occasional interruptions or impounding, that the water would be purified in a more rapid manner.

In 1894, Dr. Wyatt Johnson, bacteriologist of the Provincial Board of Health of Quebec, reported at a meeting of the American Public Health Association the results of the bacteriological investigations made with reference to the waters of the Ottawa and St. Lawrence Rivers in regard to sedimentation. He calls attention to the fact that local conditions influence sedimentation owing to variation in temperatures.

Sedimentation is naturally more marked in waters carrying a large amount of suspended matter than in clear waters and is greater when the sediment is dense than when light and flocculent. The conditions also are influenced by the keeping capacity of the water when stored.

At the foot of an aqueduct is a basin or pond about 15 feet deep, called the settling basin, and containing 23,000,000 gallons of water. The daily consumption in Montreal is 18,000,000 gallons, and double that amount is used for turbines, hence the chance for sedimentation is very unfavorable.

August 7 and September 12, at the basin there were 168 bac-

teriological colonies per cubic centimetre, while at the intake there were 84 per cubic centimetre.

The lower reservoir has a capacity of 35,000,000 gallons and 20 to 25 per cent of this is replaced by fresh water. The conditions are more favorable for sedimentation than at the settling basin.

The results of bacteriological examinations made monthly for a period of eleven months showed an average of 178 colonies to the cubic centimetre in the water at the basin and an average of 72 at the reservoir, showing a reduction or disappearance of 42 per cent of the organisms present in the supply. It was found that the bacteria varied inversely with the rapidity of the current.

In examination of the waters of the Ottawa river he found that water taken from a small lake in the course of the river and a few miles above Ottawa contained 20 bacteriological colonies. In the river between the lake and the city this number rose to 157. Some miles below Ottawa the number rose to 1,530 on one occasion, and on another to 520 as a result of the pollution of the river from the sewage of the city, notwithstanding the large volume of water in the river, (60,000 cubic feet per second) the volume of the sewage, however, not being estimated. This increase of bacteria gradually subsided, and at *fifty* miles below Ottawa the number had fallen to 48.

In the endeavor to modify the process of mechanical filtration in order to avoid infringement upon the patents of the New York Filter Company, the other companies introduced into their processes the holding of the water for a certain period after the addition of the coagulant, and before it enters the filter. This was accomplished by the introduction of weirs either perpendicular or horizontal, causing the passing of the water to be retarded sufficiently to permit of a certain amount of sedimentation. However, injunctions were repeatedly granted, restraining the use of the precipitant in this manner, it being ruled by the courts that inasmuch as the same amount of water was continuously supplied, that there was no cessation of the movement of the water, and hence the flow was continuous and was a part of the patented process.

In the introduction of the preliminary sedimentation tanks in the experiments carried out at Louisville, it was discovered that the precipitation which occurred was very material in amount, and, in fact, was absolutely essential for the practical use of the filter, owing to the amount of suspended mineral matter in the river water.

In the form of detention or precipitation tank used by the Morrison-Jewell Filter Company, the sediment tank was placed below the sand bed tank, and was round. The precipitation was at times accompanied by the formation of masses or balls of the coagulant and organic matter. These flocculent masses appeared to be the result of the rotary motion acquired by the water in the precipitation chamber. Professor Mason, of the Troy Polytechnic, calls attention to this peculiar action, and claims that the rotary motion of the water with the chemical ingredients produces a more rapid and complete precipitation than when the fluid is moving in a direct line or when at rest.

Whether this action takes place as the result of the molecules of the chemical being brought into more rapid contact with the other ingredients or whether attrition of the particles causes agglutination from the centrifugal action is not explained.

The evident impracticability of introducing the water of the western rivers directly upon a natural sand bed for filtration necessitates a preliminary sedimentation for a long period. Hours will not suffice, the time must run on into days.

The experiments now being carried on by the Louisville Water Company, and under the direction of Mr. George W. Fuller, formerly of the Lawrence Experiment Station, are for the determination of the most expeditious method of attaining the best results in this way: A sedimentation is allowed for varying periods, the time at present being five days. The decanted or siphoned water is then passed to the surface of the sand beds for filtration. The resulting filtrate, however, appears with a slight milky opacity, due to the microscopic particles of mineral matter, which are so small as to be able to pass through the interstices of a filtering media which will retain *bacteria* to the extent of over 99 per cent. The size of these particles have been estimated by Mr. Fuller to be at least one-sixth the size of the average water bacteria. This fine material can be removed by the addition of alumina before filtration, but as it it the purpose of the experiments to avoid the expense attending the use of this chemical, it is Mr. Fuller's endeavor to dispose of this by other means if possible.

In this connection it is interesting to note that by this preliminary sedimentation of five days, from sixty to eighty per cent of the bacteria are removed. This would support the theory that the re-

moval of the bacteria was a mechanical process, the organisms adhering to the organic matter for their support or food, and the organic matter being carried down by the precipitation of the mineral matters. Also, the use of alumina does not bring about a chemical change upon the bacteria, but uniting with the organic matter and the carbonates in the water forms a flocculent mass which from its weight carries the suspended matters to the bottom. This is verified by the laboratory experiments where it is shown that the bacteria continue to thrive in a strong solution of alum.

An interesting result in sedimentation is to be found in the operation of the plant used by a small town located across the river from Cincinnati. Provision has been made for storage in two reservoirs of a three million gallon supply. The water is drawn from either of these two reservoirs into a third which is the delivery reservoir. In this way the water may be held for a longer or shorter period until it is deemed sufficiently clarified to draw off, this varying with the turbidity of the waters in the river. It is the custom to allow for precipitation for a period of thirty days.

The result is quite satisfactory, disposing of a large percentage of the suspended mineral matter. Naturally the cost of such a plant is greatly enhanced owing to the large area of storage necessary.

As an illustration of the variance of waters seemingly having the same origin and similar composition, is shown in a comparison of the waters treated at Cincinnati and those treated at the experiment station located at Pittsburg. At the latter place the waters have the same appearance as at Cincinnati, yet upon passing the water through the same depth of sand as without any chemical treatment, the water appears clear and sparkling and free from any milkiness as that passed through the two mechanical filters or through the Worms filter, all of which are being tested at the same plant. If the rate exceed three million gallons per acre in the twenty-four hours the milkiness will commence.

When the report of the Louisville experiments, which are being prepared for publication by Mr. Fuller, are issued and the report of the Cincinnati work is completed, and the results of the experiments at Pittsburg, which are practically completed, become available we shall have much valuable data upon which to base our recommendations for either form of filtration, the sand bed or the American system.

DISCUSSION.

The President. Mr. Clark, will you say something upon the subjects suggested by Dr. Swarts' paper?

Mr. Clark. The larger part of the paper is devoted to the subject of mechanical filtration, which I confess I know very little about, having had but little experience in that line. Dr. Swarts spoke about sedimentation being necessary before filtration by natural sand filters, and I understand that they intend to have that at Louisville, where they are expecting to install mechanical filters. We have with us Mr. Weston, who was associated with Mr. Fuller during most of the Louisville experiments, and I think he ought to be able to tell us something about mechanical filters, and the plant they propose to install at Louisville.

Mr. Robert S. Weston. I am not prepared to say very much on the general subject of mechanical filters. Mr. Fuller's report will be published in about twenty days, and you can then get the whole matter at first hand without having it filtered through me. I would like to say some few things, however, about the removal of bacteria by sedimentation and the removal of suspended matter by sedimentation.

Perhaps you know, and perhaps you do not know, that linked with the sanitary problem in Louisville, of removing the bacteria, which average about 40,000 per cubic centimetre, is the problem of removing about 46 tons of suspended matter on the average, and as high as 175 tons, I think per day, for a supply of 20,000,000 gallons.

To show what sedimentation will do, I will call your attention to quite an interesting plant in the city of New Albany, Indiana, directly opposite Louisville. On what are called nobs or bluffs back of the city they have installed three reservoirs, on three separate hills, so that the water will flow from the highest reservoir into the intermediate one, and from the intermediate one into the lowest one, and from this lowest reservoir to the town. That water, which is of course the same in character as is supplied to the city of Louisville, at present flows through these reservoirs in about one month, and becomes a very satisfactory water at the end. It may be especially judged so from the fact that they have very little typhoid fever in New Albany, less than thirty cases, I think, per 100,000 per annum, and although they receive the sewage of the city of Louis-

ville in their supply, while Louisville, which takes its supply above itself and above New Albany, has from seventy to seventy-eight cases per annum per 100,000. This shows the efficiency of a settling reservoir as a sanitary measure.

The filter plant proper in Louisville has not been decided upon, I think I may say, without any danger of being contradicted, the principal part of the construction work there being the construction of the necessary clear water basin and of the pumping machinery and standpipe necessary to restore the loss of head which will take place if filters are installed. The plant they have designed will be quite extensive—this has been given in the daily papers of Louisville—and it is to have a capacity or 25,000,000 gallons per day. The water is now stored in a 100,000,000 gallon reservoir, which is divided through the middle by a partition wall. It is proposed to take the water from this 100,000,000 gallon reservoir after it has settled there about four days, and pass it through filters of some type, probably the American type, though I have no authority to say they will use that type to the exclusion of any other. But Mr. Hermany says he is satisfied that some filter will have to be established there which contains devices for cleaning the sand, other than those in use on the European type of filter. You can readily understand that, when you consider the immense weight of suspended matter in the river water.

The bids were opened for this clear water basin on September 1st. The idea is to take the water from the present reservoir and run it through the filters, and from those into the clear water basin which is to be located under the filters, and then the water will be repumped into the standpipe.

The extremely small size of the particles of suspended matter in the waters of our western states has been often spoken of, but I think those of you who have never seen the western rivers have little conception of the extreme fineness of that suspended matter. The Merrimac river for instance, when it gets on a rampage, brings down a good deal of suspended matter, but it is a crystaline suspended matter, and after standing some time the water will settle out comparatively clear. I have kept samples of water standing in the laboratory at Louisville from four to five months without becoming clear. It has been stated by several eminent authorities that these particles of clay stand midway between a

simple suspension and a solution. That is, the clay is so expanded, we may say, so swelled, a good deal as starch is swelled when it is diluted or soaked in water, that it is almost impossible for it to settle out of solution. But, whatever the theory of the matter may be, the fact remains that the clay in that water is very hard to precipitate. To do it the filter companies which have experimented there have used sulphate of aluminum, which, reacting with the lime in the water, produces the nitrate of aluminum, and by its sedimenting and developing and coagulating, and by other actions which may be induced in the suspended matter, it causes a clarification of the water, and also forms a film on the surface of the sand and around the grains of sand, which makes the filter act as an extremely fine strainer for the suspended matter and for the bacteria.

A competitive trial of the different systems of filtration, as you will see in Mr. Fuller's report, was conducted at Louisville from the 1st of September, 1895, until the 1st of August, 1896, with varying degrees of success. A great many problems were met for the first time, and there were partial successes and partial failures, but a great deal was learned; and then the summer of 1896 and the time along until the middle of the winter was spent in writing up the report of those experiments. The following spring, at the instigation and advice, I think, of Professor Mark, the Superintendent of Schools at Louisville, and Professors Brownell and Palmer of the Manual Training School at Louisville, a plant was set up in the laboratory for the preparation of the coagulant by electrical means rather than by chemical means. Of course, when the sulphate of aluminum was put into the water it reacts with the dissolved alkali, the lime, in the water, and nitrate of aluminum is produced. Now, this same nitrate can be produced if you put two plates of the metal aluminum, or if you put two plates of iron in the water and pass an electrical current through the plates, it has exactly the same effect, and equally good results can be obtained from it. The difference in practicability is one of dollars and cents; and to what extent you will see from Mr. Fuller's report when it comes out.

Those experiments continued until the next summer, the 1st of August, 1897, and then the rest of the time was spent in gathering together all the data which had been obtained by those experiments.

All I can say about the Louisville work, all I am allowed to say as a subordinate, is this: That sufficient data have been gathered together so that an engineer can go to work and design a plant for the city of Louisville which will filter the water of the Ohio River in a sufficiently economical manner to be practicable. But if Mr. Hermany, the Chief Engineer of the Louisville Water Company, had gone to work and designed a filter plant with the data that the filter companies were ready to furnish him in 1895, the plant would have been a miserable failure, on account of being inadequate to handle the water at times of greater supply.

Mr. William H. Thomas. As I understand it, a sand filter to be effective must have the film formation first. I should like to ask Dr. Swarts if that is correct?

Dr. Swarts. The idea used to be that the scum formation was absolutely essential, and that that was the filtering medium. If the scum were removed a certain amount of filtration would go on, but it would not give as perfect a result as with the scum.

Mr. Thomas. If that is so, what is the need of the graduation of the sand bed?

Dr. Swarts. In mechanical filters the sand grains are all the same calibre, and they are mixed up so that what is at the bottom may be at the top; whereas in sand bed filters, as I understand it, the larger stones are placed at the bottom, the next layer being smaller, and the smallest being at the top, and that acts as the filtering medium.

Mr. Weston. There is no graduation of the sand in a sand bed filter; there is simply a graduation of the bed under the sand.

Mr. Clark. I do not think the scum on the surface is always necessary. It is a very effective part of a filter bed, but if you run a filter long enough you will find that the organic matter from the water is left not only upon the surface, but it passes down through to a certain depth and coats the sand grains. Of course the amount on the sand grains diminishes as you go down, but still there is enough of the coating left so you have it a number of inches deep. So when the surface scum is removed from the top the filter is still efficient.

Mr. Codd. I would like to ask to what depth this scum is found on the sand?

Mr. Clark. That is pretty hard to say. It diminishes as you

go down, of course, and it dimishes very rapidly. But after a filter has been in use three or four years, with the same sand in it, you will find sand grains down to a depth of two or three feet with an appreciable coating. And after a certain amount gathers there it seems to stay about the same without increasing or decreasing. Of course if the filter is overworked, too much water passing through it, it will clog to a considerable depth, and the sand will have to be removed to a considerable depth. We have filters in use at Lawrence which have been filtering water for five years, and there are at least 44 inches of the original sand still in those filters, although the under grains are coated to a considerable depth.

THE OCCURRENCE OF CRISTATELLA IN THE STORAGE RESERVOIR AT HENDERSON, N. C.

BY ROBERT S. WESTON, CHEMIST AND BACTERIOLOGIST,
WEST SUPERIOR, WISCONSIN.

[*Read Sept. 15, 1898.*]

On the 14th of last July, the writer was called in by the Henderson Water Company, Henderson, N. C., to investigate the cause of, and prescribe a remedy for the bad odor which prevailed in the water supply during the summer months.

A short investigation was therefore conducted with the following results: In a few words, the water supply of Henderson is from impounded, spring fed brooks, which latter drain a sparsely settled watershed. The population of the watershed is 509.

Most of the population is housed in the corporation dwellings belonging to the Henderson cotton mill, 6,600 feet distant from the head of the reservoir. The rest of the population consists of farmers and the residents of Andrews avenue, who live in the vicinity of the standpipe.

The sanitary census of the watershed has been prepared as follows:

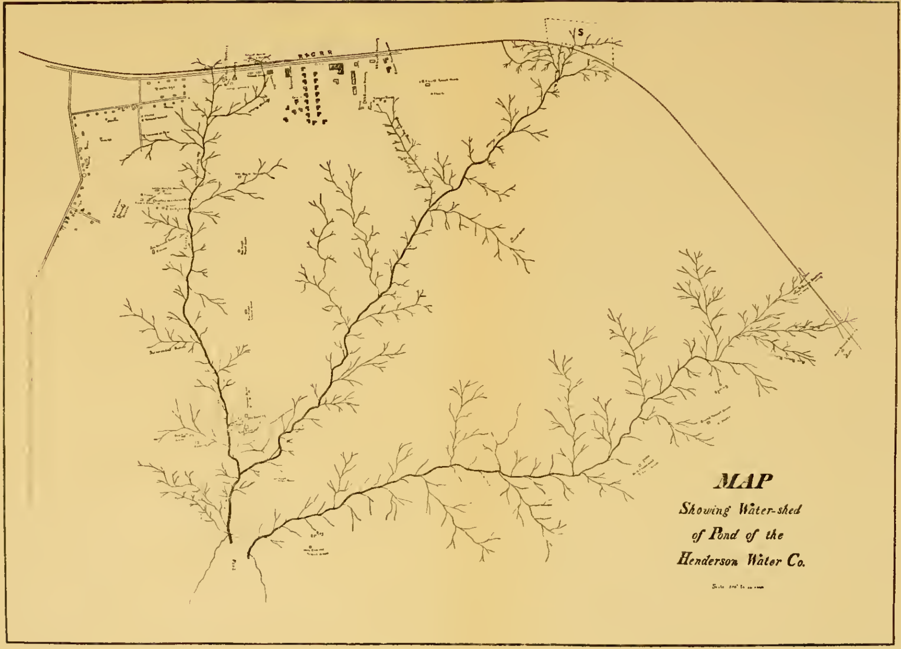
Number of square miles in watershed	2.32	
		Per Square Mile.
Persons living on watershed	509	219
Horses " "	34	15
Hogs " "	67	29
Cows " "	35	15
Privies on "	87	37
Wells " "	29	12
Marshes " "	2	
Pastures " "	9	
Sewage disposal field "	1	

A sanitary map was prepared to show the sanitary features of the watershed.

It is readily seen from this that the possible sources of pathogenic pollution are few, and easily controlled.

No privy is within 150 feet of any brook which is a feeder of the reservoir.

The thing which had the most significance from a sanitary standpoint was, that the contents of the town privies were used as a ferti-


R. & C. R. R.
S
MAP
Showing Water-shed
of Pond of the
Henderson Water Co.

lizer on the area marked S; this objectionable practice was easily stopped by the city authorities.

The Raleigh and Gaston Railroad follows the ridge which separates the watershed of the Henderson Water Company from that of the Roanoke River, and only a few rivulets on the other side of the railroad drain into the source of supply.

Owing to the sandy soil on the watershed, very little of the water in the feeders is surface water, except during the freshet seasons.

The springs, which are the main source of supply, furnish water of good quality themselves, but during the spring freshets the water contains the washings from the arable land; the feeders also receive a small amount of swamp drainage which brings with it organic matter and iron.

The three main feeders flow into the reservoir which is formed by a masonry dam in the brook below. The reservoir has an area of about 35 acres and is less than 10 feet maximum depth.

Analyses of the water have been made as follows:

Chemical Analysis by W. A. Withers, A. M., Chemist North Carolina Board of Health.

Sample collected January 8, 1898.

	Parts per 1,000,000
Residue on Evaporation	56.
Alkalinity	7.2
Chlorine	4.3
Free Ammonia	0.067
Albuminoid Ammonia	0.020

Bacterial Analysis by W. T. Pate.

	Bacteria per c. c.
Sample taken Nov. 5th, '97	78
Sample taken Feb. 5th, '98	184

Owing to the great surface exposed in proportion to the cubical contents of the reservoir, and to the fact that the water is a ground water containing vegetable matter in solution and stored in the sunlight, large numbers of organisms make their appearance during the heated term and the water takes on a disagreeable odor in consequence.

An effort was made to discover the particular organisms which should be the cause of the trouble.

There was no appreciable odor in the water July 16th, when the writer began to investigate.

Several microscopical analyses were made with the results given below:

BIOLOGICAL EXAMINATION.

SAMPLE NUMBER.	1	2	3	4	5	6
Date of Collection.	July 16. 1898.	July 18.	July 19.	July 20.	July 26.	July 28.
DIATOMACEÆ.						
Asterionella..........						
Cyclotella........	8	36	14	24	40	48
Melosira..	6	8				2
Navicula.............		4	2			
Nitzschia............						
Stephanodiscus..						
Surirella..						
Synedra......			4	2	16	30
Tabellaria...						
CHLOROPHYCEÆ.						
Closterium............						2
Cosmarium.......	2	6				
Pediastrum.......					32	14
Raphidium............					8	10
Scenedesmus..........	8	62	8	4	24	78
Staurastrum..	2	18		6	2	30
Conferva......						
Protococus............	4	136	12	18	32	244
Arthrodesmus.......						4
Allodorina............				6		
CYANOPHYCEÆ.						
Anabaena.......					68	104
Chroococus.........	6	4				
PROTOZOA.						
Dinobryon...........						
Mallomonas		8	6		2	2
Peridinium.......						
Synura.						
Trachelomonas.	6	10	2		4	4
Uroglena............						
Amoeba...............					2	
Paramecium...........				2	2	2
Englena..............		14	4		2	6
Chaetoglena....	4	4		12	2	8
Phacus...............		2				
Peranema...						6
Total Organisms.........	46	312	52	74	256	594
AMORPHOUS MATTER.	Pr.	Pr.	Pr.	Pr.	Pr.	Pr.
MISCELLANEOUS BODIES.						
Insect Parts..........	Pr.	Pr.	Pr.	Pr.	Pr.	Pr.
Ova and Zoospores ..	28	22	22	14	10	8

Pr.=Present.

No trace of cristatella was found in the samples by microscopical methods.

The figures are to show the number of organisms per cubic centimeter.

These absolutely failed to account for the odor in the water.

July 16th, a growth of cristatella was discovered (C. mucedo) on the sides of the outlet flume.

July 18th, the water had an odor exactly similar to that of the crushed masses of cristatella.

This state of affairs continued as long as the writer remained in Henderson. The odor however increased and decreased directly as the temperature and inversely as the amount of rainfall.

By July 20th, the masses of cristatella had grown to enormous size, especially about the piles which are driven on either side of the suction pipe.

A boat could be filled in a short time with the yellowish white, translucent colonies, many of which were a yard in diameter.

Subsequent tests with these colonies showed that they imparted the disagreeable odor to the water and that it was a secretion of the organism and not the organism itself which was the specific cause of the odor.

Whether this odor is the odor of the fæces of the organisms or not, I am unable to say.

Cristatella occurs at Henderson every summer, and the organism grows in noticeable amount between July 1st and September 15th. This year the appearance of the odor was delayed as is explained below.

Cristatella, or to be more specific, cristatella mucedo is one of the polyzoa or "moss like" animals, called so from the appearance of its colonies. The life history of cristatella is about as follows:

The adult individual is a colonial, worm-like animal with the digestive tract flexed on itself so as to bring the anal opening very near the mouth. This mouth is surrounded by finger like tentacles, and the tentacles in turn are covered with cilia (or hairs.) These cilia are capable of producing currents of water about and in the mouth of the animal, thus bringing its food within reach.

The animal has a very simple circulatory system, the blood being in one cavity, and each individual has both male and female sexual organs.

The large colonies mentioned above are produced from the parent by the process of budding. At the same time statoblasts or winter

eggs are produced, some of which survive the animal and the next winter season. These statoblasts are flattened spheroidal bodies, surrounded by a row of hooks which serve to fix the egg to some convenient spot.

The outer rim or ring consists of float cells and the egg substance is held between two watch glass like covers.

Many of these statoblasts can be observed floating on the surface of the water during the summer, but because they float they are not likely to be pumped into the mains, the intake being 8 feet below the surface.

The next season these statoblasts hatch and produce a free swimming cristatella, which soon attaches itself to a favorable spot and produces in turn a new colony by the process of budding, thus completing the cycle of its growth.

On account of its size and habit of growing in colonies, it is not surprising that the microscopical analyses did not reveal their presence.

The colonies grow about or are attached to articles on the sides and bottom of the reservoir, as is well known to you all. The individuals are imbedded in a structureless jelly, each having a cell out of which it can raise itself slightly. This jelly is analagous to the shell of an oyster or barnacle and is therefore the habitation of the animal.

Cristatella is strictly an animal organism and is dependant for its growth upon :

(*a*)—Food.

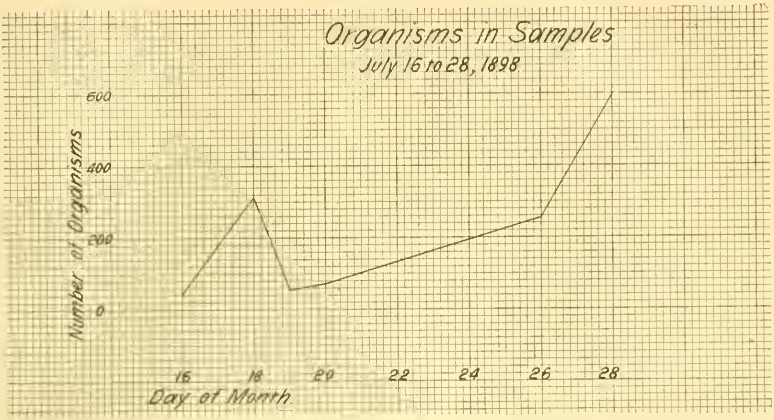
(*b*)—Temperature.

(*c*)—Sunlight.

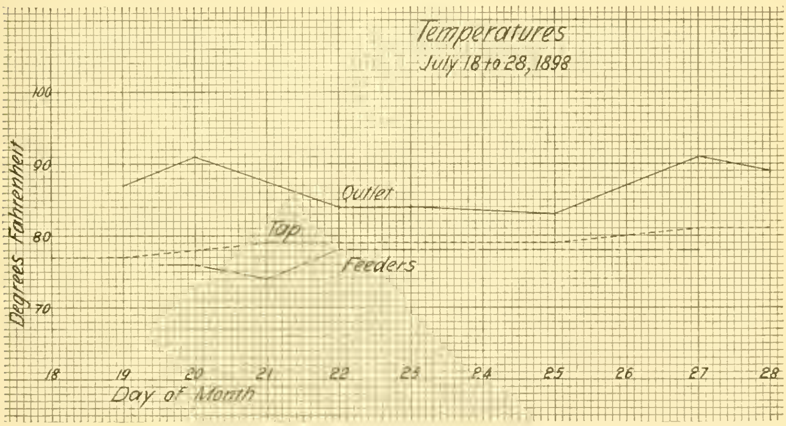
(*a*)—Its food consists of the organisms present in the water at certain seasons of the year.

It evidently grows best when the other organisms are most abundant, *e. g.* July 16th, when there were only 46 organisms per cubic centimeter of the water, there was no considerable growth and no appreciable odor, but two days afterwards, when the organisms numbered 362, the evidences of cristatella were unmistakable.

(*b*)—The temperature seems to be the chief factor which determines the growth of cristatella.



It seemed, from the short experience at Henderson, that the temperature of the water must rise to about 85° F, before any marked odor was produced. The curves plotted for temperatures and days are given below, and it can be stated that the high points are coincident with the strongest odor.



With such a shallow reservoir, the water is frequently changed, but between July 18th and 25th, when the average daily flow was about 3,000,000 gallons, the increase in temperature, due to absorption of heat in passing through the reservoir, varied between 10° and 15° Fahr.

This year the appearance of cristatella was very much delayed.

This was undoubtedly due to the unusual amount of rain, and the consequent increased flow through the reservoir, it being apparently impossible to heat such a large body of water high enough to induce the growth of cristatella during the short time it remained in the reservoir.

(*c*)—Cristatella grows only in the light and is an organism of annual occurrence.

Such was the difficulty at Henderson, and the problem presented was to remove the odor caused by the growth of cristatella and the turbidity and pollution due to the spring freshets.

As the ground water in the vicinity of the pumping station could not be utilized for the amount of money at the disposal of the Henderson Water Company, owing to the character of the water bearing strata, the writer planned a filter plant in combination with an ærator, and recommended the Warren filter as best suited to the purposes. There is nothing especially novel about any of the features of the plant, except perhaps the ærator. The ærator rests on top of the settling basin of the Warren filter and consists of a series of shelves arranged in the form of a pyramid.

The base of the pyramid is 5 feet square and there are four shelves on each face of the same.

On the edge of the shelves are strips of brass which are arranged so that they can be adjusted in such a way as to permit the water to fall in a thin sheet or in drops to the shelf below.

The whole ærator sets in a tank which in turn rests on the settling basin.

The water from the pump passes through the ball nozzle at the top of the ærator. It then impinges on the copper plate above and falls back down over the shelves into the tank.

The water then passes through the filter into a clear water basin and is thence pumped to the town. Ample contact with the air is thus provided for and the cost of pumping water the few additional feet higher necessary is less than that of a compressed air plant furnishing 1½ gallons of air to every gallon of water treated.

The size of the filter is 12½ feet and the nominal capacity of the whole plant is 300,000 gallons daily.

At present the water has an odor like that of decaying oyster shells and the improvements will undoubtedly be appreciated by the community and authorities during the summer of '99.

DISCUSSION.

THE PRESIDENT. Gentlemen, Mr. Weston's paper is now before you for discussion.

MR. HASKELL. I would like to ask Mr. Weston if the presence of 100 anabæna per cubic centimeter in the water made any perceptible odor?

MR. WESTON. I did not detect the characteristic odor of anabæna at all, excepting when we concentrated the organisms. We concentrated a half a litre or pint of water down to half an ounce for analysis, and in that concentrated mass we were able to detect the odor of anabæna, but in the tap water I detected no such odor. It has a peculiar odor as you know.

MR. HASKELL. I would like to ask how far the water passed after it got into the pipes before it reached the tap; that is, the length of time it would probably be in darkness instead of light.

MR. WESTON. I couldn't tell you about the length of time without some calculation. The main pipe from the pumping station to the town is a 12-inch pipe, and the daily consumption is only 75,000 gallons. I think the tap I took the water from is 11,000 feet from the pumping station, and I should say the water would be in the pipe at least a day and a half.

THE PRESIDENT. Mr. Hollis, won't you say something on the subject?

MR. HOLLIS. I was particularly interested in what Mr. Weston said about the presence of these organisms escaping detection, owing to the fact they were not brought in through the pipe. That emphasizes what we find to be true of many growths, that field work must be combined with the laboratory work oftentimes in order to detect the real cause of an existing trouble. Many times these minute organisms are localized and occur from some particular local cause. It is interesting to know that Mr. Weston had the same experience with the larger organisms, for most of our experience has been with the smaller growths.

MR. HASKELL. I would like to ask if, before deciding to use the Warren filter for this purpose, Mr. Weston made any study whereby it became evident that a mechanical filter would be cheaper or more expensive than a properly constructed sand filter?

MR. WESTON. It happened the water company could purchase

a second hand Warren filter, and that largely determined the policy of the company. I think without a doubt a sand filter would have cost a great deal more. For the removal of organisms I think a filter can be run at a much higher rate than for the removal of bacteria, because in this case the filter acts as a strainer, nothing more or less, and it is expected to have no other action. We haven't got to wait for the film to form around the sand before it will operate. We haven't got to wait for the settlement of any amount of suspended matter. The point is that the ærator does the work of removing the odor, and the filter strains out the organisms, thus preventing the further formation of the odor. The cost of the mechanical filter plant, which is now in the process of construction there, is estimated at about $7,000. I think $35,000 an acre is a fair estimate for a sand filter, and, if I am not mistaken, about a quarter of an acre of ground would have been required.

Mr. Haskell. Is it not really more important, in the case of a water supply of this character, to entirely remove the bacteria than it is to remove the organisms?

Mr. Weston. As I remember the bacteriological analysis of the water made by the State Board of Health of North Carolina, there were 230 bacteria organisms per cubic centimeter in the water, which is not considered at all excessive for surface water. The water is practically a ground water, and were it not for the washings of the arable land and the storage in the reservoir, it would be an excellent water. It has no color at all, or a very slight color, and is a pleasant drinking water, soft and palatable, but the plant was badly designed. It seems to be the idea of some contractors who put up water works, that if they erect a standpipe and lay their distributing system, and then run a suction pipe out to where it is a little damp, they will have a good water supply. And so they dammed up this pond, which is only 4 feet deep for the main part, and less than 10 feet deep at the deepest place. Such a reservoir, of course, furnishes the best conditions for the growth of organisms. Then to make the matter worse, the original builders of the pumping plant built it at the foot of the lake, where the organisms are the thickest. At the upper end of the pond the water is fully as good as it is in the feeders, but at the lower end it is simply foul, smells like a decaying heap of oyster shells, and it is unpleasant to bathe in.

Mr. Haskell. My reason for asking the question is that I judged here was a watershed which would be very liable to get impregnated with typhoid germs. It seemed as though there would be quite a population which might perhaps contribute infection to the plant, and that the dangerous element, which we have to fear in our water supplies, would not be as likely to be eliminated by this process. as by a good sand filter.

Mr. Weston. In making the sanitary survey of the watershed, Mr. President, that matter was looked into quite carefully; and, while there might be some danger, there is no privy which is located within 100 feet of any visible stream on the watershed. The soil is a fine sand, and it might be said that the whole region is an excellent filter to begin with. If there were any pollution there I hardly see how it could get into the reservoir. The climate also is in our favor, because in North Carolina they have no snow to wash down from the sides of the valley into the streams in the spring, carrying with it all the dejecta which may be thrown on it during the winter. Then there is another factor, that a mechanical filter well managed will remove a large per cent of the bacteria in water. Having these two facts before our minds—the fact of the natural protection afforded by the sand of the watershed, and in addition to that the mechanical filter—I cannot see how the sanitary features of the problem are of very much consequence.

Mr. Haskell. What is the death rate of the population per ten thousand from typhoid fever if you have information as to that?

Mr. Weston. I am unable to give you any facts about that at all.

Mr. Chace. My father was a physician, and I used to hear him say that when a sufficient cause for a man's death was found, it wasn't worth while to look further; for instance, if a man's head was off that was sufficient to cause his death, and there was no need to look for anything else. I understand in this case Mr. Weston was called in to ascertain the cause of a bad odor which was giving a great deal of trouble. He found that cause and found means of removing it. He did not look for typhoid fever germs because there was no trouble from them.

RESULT OF TUBE WELL EXPERIMENTS IN LOWELL, MASS.

BY GEORGE BOWERS, C. E.

[*Read Sept. 15, 1898.*]

Our experiments with driven wells in Lowell were brought to a close on the completion of the third group of tube wells in April, 1897. A description of the first well plant may be found in the Journal of this Association, Vol. IX, No. 2, and of the second in a paper read before you February 12th, 1896. I will now give a brief description of the third group which were constructed under contract by B. F. Smith & Brother of Boston, Mass.

This plant is located on a strip of land lying between the Pawtucket Boulevard and the Merrimac River and owned by the city. It was here that Mr. Andrews made his last tests on the boulevard, as described in my first paper. A line of wells was laid out and driven about 34 feet south of the south line of the boulevard and parallel to it, being about 500 feet from the river. Sixty wells were driven on this line, those on either end yielding so small an amount of water that the line was not extended. Twenty-six of these wells were connected temporarily and pumped four days, yielding 570 gallons per minute. During this test the ground water was lowered 12 feet, and later twenty-nine of the whole number were pulled up, their yield being insufficient to warrant their being retained in the plant.

Another line of 66 wells was then driven parallel to the first and 280 feet nearer to the river; these wells were connected and tested in groups of 20 each, the average yield per well when pumped in this manner being 25 gallons per minute. Samples of water collected from these wells and analyzed showed the presence of free ammonia and iron, in consequence of which they were abandoned and the pipes pulled up. Next, a line of 22 wells was driven at right

angles to those connecting with the line first driven; when these wells were tested all but five proved good.

The next wells were laid out and driven in a line parallel with the first two lines described and 170 feet south of the one first driven. In this line are 122 wells which have been tested for quantity, in groups of from 15 to 20 wells each. When the water here was analyzed, each and every well was found to be of excellent quality. The plant contains 169 2½-inch wells, which vary in depth from 27 to 40 feet. They are driven wells and a very large point was used to protect the screens in driving. The screens used here are similar to those used at our second plant and vary in length so as to correspond with the depth of the water bearing stratum at each well; this lies about 25 feet below the surface and varies in depth from 5 to 15 feet. The earth above this stratum is composed of very fine sand and river silt, which is almost impervious to water. Between this bed of water bearing sand and bed rock is a very fine sand known as quicksand, varying in depth from 30 to 40 feet, in which no water is found, even at the surface of the rock where it is generally found. The wells are connected by flanged suction pipe of the following sizes:

20-inch suction pipe	13 feet
14 " " "	1,152 "
12 " " "	326 "
10 " " "	170 "
8 " " "	130 "
6 " " "	265 "
Total	2,056 feet

On every length of the suction pipe is cast a 2½-inch branch connection, at an angle of 45 degrees to the main pipe; this causes all the pipe to be classed under the head of specials. This, we think is far better than the custom of connecting one or two lengths of pipe with a short branch special, as it greatly reduces the number of joints, a very important item in work of this kind.

The connection of the suction pipe with the well is made as follows: Into the branch is screwed a piece of 2½-inch pipe, to which a gate of the same size is attached; next is placed a piece of lead pipe about 3 feet long with a flanged joint nearest the well, and last, a piece of 2½-inch pipe of the right length to make the connection with the curved Tee joint at the well. This is a very easy way to

connect the wells, as the lead pipe may be used to correct any small error in line or grade, a difficult undertaking with iron pipe. A lead pipe should never be used for a water supply until you have ascertained that it will have no effect upon it, and as the service pipes in our city are lead, this is the first problem we had to solve.

The suction mains are connected with a large horizontal air receiver, 11 feet long and 6 feet in diameter, and each pump is connected independently with the receiver. The suction mains are laid about three feet below the surface of the ground on a pile foundation, on a true grade declining from the pumps. Great care was taken by the contractor in making the suction mains, branches, and all connections air tight. Every pipe and special was tested for air before it was laid, and to our great surprise many of them which had passed the water test were found defective under this test. Of the first shipment of pipe more than 50 per cent was found by the air test to be defective and was returned to the foundry. Most of the small specials found in stock were defective also, and the contractor was obliged to order extra heavy ones made to meet the test. All the testing for air was done in the field; this was done by connecting the piece to be tested with a pump and forcing air into it while submerged in a tank of water. That this was a wise precaution has been well proven, as this plant has been very free from air.

The air receiver is placed in the pump pit which is 26x28 feet, and with it are connected two 10x18x18-inch Blake pumps, each having a capacity of 3,000,000 gallons per day. As the pumps deliver the water into a conduit only 4 feet above the plungers, their work is very light. Over this pit is erected a temporary building, and when this is replaced by a permanent one, and permanent pumps put in, I see no reason why this plant should not be run by electricity generated at the central pumping station as economically as by a separate steam plant.

The contract for this plant was similar to that of the others, the contractor agreeing to furnish a plant capable of providing a stated amount of water per day during a year's test for a given price per 1,000,000 gallons, and, in addition to this, was paid for all the water delivered which was pumped during said year. On April 30th, my certificate was sent to the water board stating that the contract between the city of Lowell and B. F. Smith & Brother was com-

pleted, and that the contractors were entitled to the full payment for 3,000,000 gallons, also a supplementary contract for 1,500,000 gallons, making 4,500,000 gallons in all. This plant has never been pumped to its limit, the amount of water the contractors were allowed to pump each day being fixed by the superintendent of water works.

The city of Lowell has now an abundant supply of water of excellent quality. The first plant, built by the Cook Well Company of St. Louis, Missouri, was accepted and paid for as a 2,500,000 plant in September, 1893, and it has continued to supply that quantity when wanted ever since. The second plant, built by the Hydraulic Construction Company of New York, was accepted in April, 1896, as a 3,000,000 gallon plant. During its year's trial the company pumped 1,137,961,983 gallons, being at the rate of 3,109,186 gallons per day. The third, which I have just described, we call a 4,500,000 gallon plant, although it has yielded 5,000,000 and is capable of doing so when necessary. This makes a total of 10,000,000 gallons per day when running in a normal condition. This amount could, of course be increased very much in case of emergency. The average amount of water used by the city for the year 1897 was 6,594,364 gallons per day, and the average amount for the month of January, that being the month of greatest consumption, was 7,422,483 gallons per day, showing that for the present at least, we have an ample surplus.

It will be readily seen from these figures that we are not obliged to use our three plants all the time. In fact, one is held in reserve most of the time. By this arrangement any repairs can be very easily made, as either well plant can be shut off and the city's supply of water taken from the other two. The quality of the water has from the first been excellent, and now that the quantity is assured I think we may be entirely satisfied with the result of tube well experiments in Lowell.

DISCUSSION.

Mr. Fuller. I would like to ask Mr. Bowers what has been the cost of the three systems?

Mr. Bowers. About $265,000 for the three. I have a diagram here which shows the plan as originally laid out for the well plant,

and the plant as it was finally laid out. You will see that the line we now have is as different from that which was first laid out as is possible to imagine.

Mr. Whitney. What is the length of the well line?

Mr. Bowers. It is 1,500 feet long.

The President. You regard it as perfectly successful?

Mr. Bowers. I do. We can pump 4,000,000 gallons a day at any time, and we have pumped 5,000,000 gallons without any trouble whatever.

Mr. Fuller. Has Mr. Bowers considered at all what the expense of a filter plant would be of sufficient capacity to produce an equal amount of water from the river?

Mr. Bowers. We always expected to build a filter at Lowell. Some people thought they would like to know whether there was any chance for wells there, though they expected to build a filter, so we began experimenting to find out how much water could be got from wells, the idea being to filter the rest. We built one plant, and then a second, and now we have built a third, and it doesn't look as though we should build a filter. We now have a supply of 10,000,000 gallons, and we use but 7,000,000.

September 16th.

Mr. Clark. Mr. Bowers spoke to us last evening about the supply they have in Lowell from driven wells. As he stated, at the present time the supply is sufficient; but he does not know, and nobody knows how long that supply is going to remain satisfactory. As they draw on the ground more, they may get a less satisfactory supply, and they will find perhaps more iron. And although he appears to be sure that the filter question is far in the future for Lowell, I am not so sure myself. In fact I believe that it will come up in the city of Lowell as surely as the city grows. The question may not be the filtering of the Merrimac river water; it may be the filtering of the well water.

Mr. Fels. I should like to say a few words, Mr. President, as to the remarks Mr. Clark has made about the Lowell supply. Our experience there teaches us that as our plant grows older it will deliver more water. The reason for that seems to be that the more we pump from the wells the easier the delivery is. Of course we cannot tell absolutely what the yield will be four years from now, neither do we know whether the Merrimac River will carry as much

water in ten years from now as it does today. A great many people in our city said we could never get a million gallons of water a day from wells, but we have demonstrated that there is no trouble getting ten millions. And as to the cost, as Mr. Bowers told you last night, it was only about $150,000, and I believe the city of Boston has paid four or five times as much as that for its surface supply. I see no reason why the amount of water should grow less, because after all there is really no question but that it is really surface water. Last year, during the summer when there was hardly any rain for three months, our wells delivered three millions daily. We draw to a depth of from 40 to 60 feet from a territory of 35 or 40 miles, and it certainly doesn't seem as though there was any danger of a lack of supply, and our experience during four years has proved that, we think

Mr. Clark. I did not intend to say that the volume of water drawn from the wells is going to grow less year by year, but as the city grows, I suppose they will have to draw more water. Whether they can keep extending the well system or not is a question, something I don't know about—a man who has investigated it of course knows more than I do about it—but the limit will probably be reached eventually in the vicinity of Lowell, and as I have said, they are not sure that the water is going to continue to be of the same quality it is today.

SOME THINGS THAT SHOULD BE DONE IN CONSTRUCTING A DISTRIBUTING SYSTEM OF WATER WORKS.

BY WILLIAM R. HILL, CIVIL ENGINEER, SYRACUSE, N. Y.

[*Read Sept. 14, 1898.*]

In building a distributing system of water works great care should be taken in selecting the most perfect materials and constructing the works in the best possible manner to insure durability.

With the operation of the primitive works began the necessity of making repairs, and with the most perfect construction of this day we find that we are still making repairs. The question that presents itself is how can we construct a durable system and reduce the necessity of making repairs to a minimum. We should secure careful and competent engineering ability to devise the plans and specifications, the most perfect fixtures should be adopted, all the material should be made subject to a rigid inspection, and none but competent and reliable workmen should be employed.

In many municipalities but little attention is paid to the inspection of the materials. It is important that the cast iron pipe should be inspected during every stage of its manufacture, both as to the quality of the metal and the workmanship. It is not the intention to cast any reflection on our manufacturers, but still it is a fact that without a rigid inspection their employes will become careless and cause a poor material to be put on the market, even though it is the desire of the manufacturer to furnish none but the best possible; this is true not only in relation to the manufacture of pipe, but to all the materials and fixtures used.

Special attention should be given to the form of the lead groove in the hub of the pipe; it should be of such a shape that it will permit the lead to be easily driven and gradually expanded.

The pipe should be laid in a straight line and on a grade without any abrupt angles in order to insure a uniform space in the joint for

the lead. The pipes should also be in lines located a uniform distance from the center of the streets so that they can be easily found. No joints should be run or caulked until the pipe is placed in line in the trench. It might be a little cheaper to join three or four lengths of pipe together before they are lowered in the trench but there is a liability of injuring the joint. No short pieces of pipe without a proper spigot should be used at any end, as the pressure will tend to open the joint. Bends should be made by using special castings and not by using short pieces of straight pipe. There should be a block of masonry built back of all bends and hydrants as well as against the ends of all lines of pipe that are eight inches or larger in diameter. After the pipe is laid it should be subjected to a pressure test of at least one hundred pounds per square inch more than can be obtained from the ordinary pressure under which the plant is to operate. The pipe and joints should be carefully examined while they are under pressure and if any defects are found they should be corrected before the trench is filled. A section of pipe should be very slowly filled with water, otherwise it would be subject to a severe shock by the surging of the water. Hydrants or other fixtures should be open for the escape of the air otherwise it would be apt to burst the pipe.

When good pipe has been properly laid the necessity of digging up the street to make a repair should be quite remote. I think that it is fair to say that the greater number of defects found in a system of water works are the occasion of the little attention paid to the selection of the material and to workmanship of the service pipes.

All corporation and curb cocks should be made subject to inspection during all phases and processes of their manufacture. They should be made of a mixture of metal that will insure a strong and tough casting. A good casting for this purpose can be made of 88 parts of refined copper, 6 parts tin, 3 parts lead and 3 parts zinc. If there is alkali or salt in the soil where the cocks are to be used the zinc should be omitted, as the alkali and salt will corrode and destroy it.

The castings should not be allowed to cool in the sand. From 15 to 20 minutes after they have been poured, depending upon the heat of the metal when poured, they should be placed and allowed to cool in water before the sand is removed. This operation anneals the metal.

The cocks should be made strong in all their parts, with little regard to the saving of an ounce or so of metal. The plugs should be lubricated by plumbago and Albany grease or vaseline. Beeswax and tallow should not be used as it will get hard and make it difficut to open or close the valve. The finished cocks should be tested by hydraulic pressure of not less than two hundred pounds per square inch and while they are under pressure the valve should be opened and closed and examined to see if there are any defects.

The selection of an inspector should be made by considering both the practical and theoretical knowledge of the applicant. If a party could not be found with both these qualifications, I should prefer the practical man, because he could point to faulty work with great confidence, and with his years of experience, he should have some knowledge of metal. The inspector with only theoretical knowledge is apt to accept poor and reject good work.

Service pipes should be laid in straight lines at right angles to the axis of the street so that at a time of a leak the location of the corporation cock could be easily determined from the position of the curb cock. This together with the fact that the main is laid at a fixed distance from the centre of the street will enable the repair to be made with the least possible disturbance to the pavement.

If the service pipe is of lead all the solder joints between the main and curb should be made in a shop, as better work can be done there than in a trench. To one end of the pipe the tail piece of the corporation is soldered, while to the other end the curb cock and a piece of pipe about a foot long is attached. The pipe is then coiled up and taken to the trench where it is to be used. The tail piece is attached to the corporation and the service is complete to a point one foot beyond the curb cock where the joint connecting with the service to the building is made. None but the best of solder for the purpose should be used. The service pipe between the main and the curb should be made of one piece and no unnecessary joints should be permitted. All short pieces of lead pipe can be melted up and used for caulking joints in cast iron pipe.

A service pipe should not be laid in the same trench or close to a sewer. It would be hard to discover a leak should one occur in such a service, as the water would not appear on the surface of the ground but would find its way to the sewer.

Where a sewer or other trench is excavated crossing under a lead service-pipe, the pipe should be properly supported, as when the trench settles it would carry the pipe with it and would be apt to cause a leak at the nearest joint.

Fire hydrants should not be used as fixtures to fill sprinkling carts with water, unless they are provided with a special valve and nozzle for that purpose. Such a valve and nozzle can be made in the dome or cap of the hydrant. During the season when sprinkling is done the drip is closed and main valve in the hydrant is slightly opened so that there is a constant supply of water in the barrel of the hydrant. The men who sprinkle cannot interfere with the main valve or nozzles as their wrench will not fit them. To use these hydrants for fire purposes the firemen first close the main valve with three turns of the valve-rod. They cannot make a mistake and take off the upper nozzle as that requires a smaller wrench. No one but a fireman or an employe of the Water Department should be permitted to have a wrench that will open the main valve. These special hydrants should be placed at points convenient for the purpose of sprinkling. In the city of Syracuse, N. Y., there are two hundred that have been in use two years, and have been very satisfactory, both to the Water and Fire Departments.

A frequent cause of trouble with hydrants is because they are not properly drained to a sewer. If this connection were made with a lead or wrought-iron pipe there should be no liability of the hydrant becoming frozen.

The establishment of a system of water works with the best material and workmanship, will result not only in a saving in the cost of repairs to the plant and to the pavements, but there will also be a saving in the cost of pumping water that would be lost in leaks, and this might be considerable.

In conclusion let me say that it is to the great credit of our manufacturers that they have kept their products up to the present standard. If poor goods have been used it is in a great measure the fault of the purchasers, who have accepted the lowest proposal for furnishing goods, without any inspection of the metal or weight or workmanship of the fixture, and have rejected the proposal of parties who have given their product a life's study, and have struggled in competition with others who furnish fixtures of light weight, poor workmanship and of a metal composed of a mixture of scraps.

DISCUSSION.

The President. Gentlemen, Mr. Hill's paper is now open for discussion. He has covered quite a wide range of topics, and I think there ought to be something said upon some of them.

Mr. Fuller. I would like to ask Mr. Hill in regard to his hydrant, what make it is and where it can be obtained?

Mr. Hill. The hydrant we use is the Eddy, but the fixture of which I spoke can be attached to almost any hydrant.

Mr. Chace. Mr. Hill spoke of the form of groove of the hub of the pipe. There are two forms in common use, that in which the section is semi-circular, and that in which the section is a V. I should like to ask what he prefers and his grounds for preferring one over the other.

Mr. Hill. I prefer the one which you have described as in the form of a V, the inner surface of the hub being for about an eighth of an inch or quarter of an inch parallel with the face of the pipe, then curving inward about three-eighths of an inch in a distance of an inch and a half and then outward again in about half an inch of distance.

Mr. Chace. The reason I asked the question was that I have heard it claimed as an objection to the semi-circular form that, after the joint had been poured, when the lead was caulked it would be driven by and cut off. And that the V-shaped avoided that difficulty. Now, practically, I don't think it makes any difference what form that groove has. I have had occasion to take up a good many pipes, and I have seen joints with the semi-circular form which were entirely perfect, that hadn't been driven by at all; and practically, in the form of the hub, the founders do not succeed in getting the theoretically perfect form of V which should be desired. So I really believe you get fully as good results from the old-fashioned semi-circular form.

The President. The depth of bell is usually a prolific source of discussion, and I believe there is a wide difference of opinion among the members as to the proper depth to use on the same sized pipe. Will you say something on that subject, Mr. Whitney?

Mr. Whitney. I am not prepared to say much on the subject, but of course we all know that there are hardly any two adjoining localities where they use precisely the same pattern or the same

depth of bell. While some people think that about 4½ inches is the right thing, others would get along with perhaps 2 or 2¼ inches. If there was a representative here from Providence I presume he would tell us about the Providence or Shedd bell, which is used there and in a large number of other places. Of course a shallow bell necessitates using more special castings than a deeper bell, but, on the other hand, you don't have to use quite as much yarn and perhaps not quite as much lead. I think an interesting paper for the Association would be one which would treat on the different patterns of bells that are in use, and the depth of lead, etc., required. The subject is certainly broad enough for one paper and perhaps for two. I would like to ask Mr. Hill what is the depth of his bell?

Mr. Hill. I prefer 4 inches. On some of our smaller pipe, 6 and 8-inch, I have used 3½, though I would rather have 4.

Mr. Hawley. We frequently see specifications which say: "Joints shall be well and properly caulked," or words to that effect; and it seems to me that a subject which might profitably be taken up here would be just what "well and properly caulked" means. We frequently find workmen differing in regard to the proper method of caulking a joint, and I would like to ask Mr. Hill what his ideas are on that subject.

Mr. Hill. I like to see the lead driven to about an eighth of an inch inside the face of the hub, for then I feel pretty well satisfied it is well driven, and with the inspection of the pipe under pressure it is a pretty good guarantee you have got a good joint. On the conduit line from Skaneateles Lake to our reservoir we tested the pipe with 100 pounds greater pressure than it can get from the lake, and examined all the joints while under that pressure. We found a great many of them which would sweat, as we term it. When we started work the contractors tried to get us to omit the clause about making the test, claiming that they had workmen who had been caulking joints all their lives, and they guaranteed none of them would sweat. Well we turned the water on that conduit line in July, 1894, and the gates at Skaneateles Lake have never been closed since. We have a patrolman walking over the line every day, but we have never found a leaky joint on the line.

Mr. Hawley. That will do very well on a conduit line where it is possible to make such a test, but on the distribution system in a

city frequently the line must be covered up so quickly that such a test cannot be made. And when it comes to the matter of inspection, the inspector finds fault with the caulking, the contractor says he is doing the work in a workmanlike manner, etc., and the question is what that consists in? Of course if a joint is driven back it is pretty good evidence that it is tight, but still if loose yarn is used it will drive. Now, what I am coming at is whether it wouldn't be a good thing to specify the working tools which shall be used, beginning with a cold chisel, and then following with the various sized tools? I have made it a practice to do that, and in cases where inspection under pressure cannot be made it seems to me that a specification of that kind would cover the matter pretty well.

Mr. Hill. I am not prepared to discuss the question as to tools, but I cannot comprehend any case where you wouldn't have an opportunity to inspect the pipe under pressure. I have laid 140 miles of pipe in Syracuse, some of it in our principal business streets, and I have always tested it before it was covered.

Mr. Hawley. I remember one case on new construction where we didn't have the pumping station built until some months after the distribution system was finished. How would you make the test then?

Mr. Hill. If you can fill your pipe with water from any source at all, having it once filled you can get your pressure from a hand-pump.

Mr. Fuller. In several cases where I have had heavy pressure, I have had lugs cast on the hydrants and also on the special casting at the other end of the hydrant branch, and simply run a rod through and put a nut on at each end. That answers a very good purpose and, perhaps, would not be as expensive as the block of masonry which Mr. Hill speaks about. I think it is a good thing to have something to hold your hydrant on, because, of course, there is one joint where there is no bead on the pipe, and if the pressure is heavy it is very likely to push the hydrant off, and the same with bends.

Mr. Hill. I quite agree with Mr. Fuller, that the rods would answer the same purpose, but they don't cast lugs on the ordinary special. I will say that in testing our 30-inch pipe where we had a special casting which formed a curve, the castings were 8 feet

long and 14 feet radius, and there were five of those put together to make a vertical curve. When I put the pressure on there without any support on the top of the pipe, the pressure lifted that 30-inch pipe right up.

MR. FULLER. I think in such cases, when conduits cross bridges, where you have to put in two eighth bends, for instance, there isn't any doubt that those pipes ought to be thoroughly strapped together; because it is usually a place where, if a leak occurs, it is apt to do great damage. I have found that out by experience. I have never had any bad accident, but I have had cases where it might have been pretty serious if it hadn't been discovered in time.

MR. CRANDALL of Burlington. I would like to ask Mr. Walker if it is his custom to test the pipe when he re-lays his cement pipe in the streets?

MR. WALKER. I do just the same as the rest of the sober superintendents do, or most of them, I guess. I lay a pipe in the street, and I back fill it, and then I trust to luck whether it will leak or not. (Laughter.) You may test it as much as you are a mind to and find it all right, and in two years' time it may leak. So I do the best I can, lay it the best I can, have it caulked the best I can and back fill the trench, and then folks won't kick about the street being dug up and all that, and if there is a leak afterward I mend it; and I guess that is the way the majority of superintendents do. (Laughter.) I don't know as I can offer anything new or make any suggestions on this subject. We have had all kinds of contractors to lay pipe and they have said that they have laid it perfectly, they have tested it and we have tested it, but after they have been away about a year I find it leaks, so I have concluded they don't do the work any better than I can do it myself. I for one never saw any pipe laid but what would leak. Others say they can lay it so it won't leak. I have heard them get up here and tell us how they can do it, that it is easy enough (laughter), but I never could do it. I am rather inclined to think that there are some cases where, do the best you can, there will be some settling. For instance, you are obliged sometimes to lay a pipe in a hurry in a pretty bad, wet place, and it is apt to settle the best you can do. I am not going to sit up nights to see if it settles, but I back fill, and do the best I can, and trust to luck, more or less. (Laughter.)

Mr. Haskell. I would like to ask Mr. Hill if he can tell us how many leaky joints he discovered, or what percentage of leaky joints, during these tests which it was necessary to re-caulk before the trench was filled?

Mr. Hill. I don't know that I can answer that, but to my best recollection in the first half mile of pipe we laid, we found in the neighborhood of twenty joints that were leaking a little, oozing, sweating as it were.

Mr. Haskell. It is very difficult to caulk a joint so it won't sweat a little bit. Of course we cannot expect to get perfect work, but in most instances that I have known of tests being made of our work it was not necessary to use a caulking iron again, and we do not expect to have to re-caulk a joint. I often put in several miles of pipe and there won't be a joint that a caulking hammer has to be used on again. While it is quite important that there shall not be leaks, and there are some water supplies which need to save all their water, so it is more important in their case than in others, still it does seem as though with ordinary care the work ought to be so well done, with an inspector on it, that there would not be a single joint from which you could see the water spurt out under a test. I have never found one such joint on our work.

Mr. Hill. I would ask Mr. Haskell if he ever has tested his pipe before it is covered up?

Mr. Haskell. We have tested a good deal of our work, until we were satisfied that the caulking we were doing was sufficiently well done so that we could feel perfectly safe in leaving it.

Mr. Crandall of Burlington. My recent observation of pipe and specials have led me to think the manufacturers are not giving us as good coating as we ought to have or have had in years past. We are getting very cheap pipe and it seems to me we are paying dearly for it. I would like to know if any other of the gentlemen present have been impressed in the same way. I have noticed that the coating we get on pipe and specials coming from the foundries is no better put on than the coating which our local founder would put on with a brush.

Mr. Walker. I think Mr. Crandall is right. It has been my opinion, that of late years they do not coat the pipes as they used to. I am satisfied that the pipe we have laid the last year is not as good as pipe was ten or fifteen years ago, so far as the coating is

concerned. The character of coating of the pipe depends upon the way the coating is done. It doesn't depend so much on the stuff they put on, whether it is tar or whatever it is, as it does on having the pipe and the coating of the right temperature when it is put on. It has got to be done at just the right time, and the materials must be at just the right heat, and then the coating will be good, whether it is tar or varnish or whatever it is. I have more trouble on account of poor coating than I do with bells or leaky joints or anything of that kind. I am satisfied that they don't coat the pipe as they used to, and I should be willing to pay two or three or five dollars a ton more to have it coated as it used to be fifteen years ago.

Mr. Hyde. I have found the same trouble that Mr. Walker and Mr. Crandall have spoken of, that the coating of the pipe is extremely poor. In fact, the coating on the pipe we have bought in the last two or three years seems to be good for nothing. My experience has been that the pipe has been growing poorer, that it has been very hard and brittle, and when we get a new lot of pipe a good many of them are cracked at the spigot end, and will have to be cut off before they can be used.

Mr. Crandall of Burlington. If I remember rightly the city of Newton used to send a man to the foundry to make a very careful inspection of the pipe they would buy. I would like to ask if that is still the practice?

Mr. Hyde. I might say that when we put in our works the first 30 or 40 miles of pipe was excellent, the bells and the spigots were fine and everything was in good condition, and so satisfactory that we had no inspector at the foundry. Since then, however, we have bought our pipe at different places and had inspectors go to the foundries and inspect the pipe. But while they have inspected the pipe and seen that the spigot and bell ends were smooth and all right, still the quality of the iron has been poor just the same. I don't know as we can help that, or as any inspector could help it.

Mr. Thomas of Hingham. Allowing that what Mr. Crandall and Mr. Hyde have said is true, who is to blame for it? Isn't it the consumer who is to blame for these poor goods? We demand a cheap article, and they give it to us. We issue proposals for bids for pipe and work, and we give it to the lowest responsible

bidder, and he is going to get out whole if he can. So I think we are really responsible for poor pipe or for poor plumber's work or materials.

Mr. Hill. I claim you cannot inspect pipe after it is once coated. If you send an inspector to the foundry during the manufacturing of the pipe the metal can be tested throughout for its transverse and tensile strength, and any defect in the casting can be found before it is coated. If your pipe is brittle and breaks like glass, your inspector has not understood his business.

Mr. Coffin. I never have experienced much difficulty with the quality of the pipe itself, but I have had the same experience that has been spoken of by others with regard to the coating of the pipe. I think the coating is very poor, and it may be that it is due to the change in the methods of coating pipes of late years. The specifications, even those that we use now, require that the bath shall be of a certain temperature, and that the pipe shall be left in it for a certain length of time; I can't give now from memory the time, but it is a considerable length of time. The founders claim it is impossible to do that, that they do not have bath capacity, or yard capacity, or skid capacity enough to allow them to leave the pipe in the bath the length of time specified. Now, it may be that this is an important feature in coating pipes, although I may be all wrong about it. I think the old specifications required that the pipe should be left in the bath something like 20 minutes, that they should be put in a temperature of 300 degrees, and that the bath should be at a temperature of 300 degrees; I am quoting from memory now, but it is about those figures. Now, as nearly as I can learn from the inspectors who go to inspect the pipe, the founders do not want to do anything more than dip it in and get the coating on it and then out with it onto the skids. It is quite possible that that method of treatment may make quite a difference. I suppose their haste is due to the fact that they are rushing out large quantities of pipe. There is a great deal more pipe made and consumed now than there was in the older days, and probably more pipe is made in a foundry of the same capacity now than formerly, and the founders are rushed harder. It has seemed to me for some time that a very serious problem, and one which required the attention of those interested in water works, is the devising of some method for the better protection of pipes.

I think we all believe in cast iron pipe, and that most of us have abandoned the use of cement lined pipe. There is no question that there are serious defects in it, and I guess there are very few who would advocate using it or wrought iron pipe for mains; but there are certain features about cement lined pipe, if it can be well made, which we must admit make it superior to cast iron. As soon as cast iron pipes are in the line they begin to deteriorate.

There is probably no question but the discharging capacity of a cast-iron pipe must grow less, must decrease, as soon as it is laid, with certain waters. Whether this is due to unsatisfactory coating or not I am not prepared to say, and I don't know as I really have any opinion about it; but it seems to be the fact that there is room here for a great improvement. I do not know how it will come. I have been considering for some time in a way for myself, and recently a little more in detail with some one else, the question of lining cast-iron pipe with cement. I do not know whether that is a practical thing to do or not, but I have examined the matter theoretically upon the question of discharge, and I find that a 6-inch pipe lined down to $5\frac{1}{4}$, (possibly that lining wouldn't be quite enough, but probably a $6\frac{1}{4}$ pipe could be obtained, and that with a half-inch lining, which would be all right,) would have the same discharging capacity in 15 years as a 6-inch coated pipe which is left in its natural condition. The decrease in the discharging capacity of a coated cast-iron pipe is so great that in about 15 years, and I think that is a conservative estimate, the discharging capacity of a pipe lined down to $5\frac{1}{4}$ would be as great as a 6-inch coated cast-iron pipe after that time. And of course we all know that the discharging capacity of a pipe in 15 or 20 years from the time it is laid is usually the measure of its value. When the pipe is new the consumption is not usually as great, and the capacity is tested some years later. I do not know and have not examined the matter enough, and of course there has been no practical test made of it, to say that it is a practical matter to line cast-iron pipe with cement; but theoretically, from the point of the discharging capacity, I believe that there will be very little difference in the pipes after a period of 15 or 20 years.

MR. RICHARDS. I think it is perfectly practicable to line a cast iron pipe down so as to make it $5\frac{1}{4}$ inches; but at first thought it seems to me it would be cheaper to get a cast iron pipe $6\frac{3}{4}$ inches

in diameter to begin with, and let it rust. It would amount to the same thing in 15 years.

Mr. Coffin. It might be cheaper but not quite as good. There is a difference between a clean pipe and a foul one besides the mere discharging capacity.

ABSTRACT FROM THE REPORT ON THE TEST OF THE SNOW PUMPING ENGINE, AT INDIANAPOLIS, IND.

BY PROF. W. F. M. GOSS, PURDUE UNIVERSITY.

Presented by F. A. W. Davis, Vice President of the Indianapolis Water Co.

5. *Duty as defined by Contract.*—The terms of your contract specify that the duty shall be expressed as the number of foot pounds of work done by the pump per 100 pounds of coal, assuming that each pound of coal evaporates 10 pounds of water. I find that in a test of eight hours duration under the prescribed conditions, 11,725,000,000 foot pounds of work were done by the pump, and that 69,862 pounds of steam were consumed by the engine, giving a duty on the basis stated, of *167.8 million foot pounds.*

6. *Duty on the Basis of a Million B. T. U.*—A more usual basis for calculating duty is to be found in the foot pounds of work done *per million British thermal units* consumed by the engine, the advantage of the basis being that results of tests run under different steam pressures may be directly compared. The engine tested performed 11,725,000,000 foot pounds of work at the pumps on a consumption of 79,093,000 B. T. U.'s making its duty on this basis *150.1 million foot pounds.*

7. *Duty Record Broken.*—The duty disclosed by the data exceeds by a liberal margin that obtained in any test, the results of which have thus far been published. It justifies the conclusion that no engine exists which can equal the performance of the engine tested. The famous Milwaukee engine, known to engineers the world over, gave a duty of 137. million which is to be compared with the 150.1 million delivered by the Indianapolis engine.

The plan of the test was not sufficiently extensive to permit a complete analysis of all the conditions affecting the work of the engine, but it would appear that the high performance is due to good work by every part of the machine. Not only is the cylinder

economy exceptionally fine but the friction losses are extremely low.

10. *Friction.*—The difference between the work done by the steam on the pistons and that delivered by the plungers, is the work absorbed by the engine in the form of friction. The data shows that but 4.6 per cent of the indicated power was lost in this way. This is unprecedently small. It is altogether probable that a more elaborate test, in which special attention is given to the indicator work, may change this figure since the relation is such that a change of one per cent in the indicated power would produce a change of 20 per cent in the value of engine friction. For the present, however, the figure given represents the best information that is to be had, and there is nothing in the data to discredit it.

11. *Steam Consumption per Horse Power per Hour.*—The performance of steam engines employed in every variety of service is often expressed in terms of the weight of dry steam required per horse power per hour. A determination upon this basis for the engine tested gives a consumption of 11.26 pounds. This, so far as the undersigned knows, is less than is required by any engine the results of which have ever been reported. It is evident, therefore, that the engine excels both in the domain of hydraulic engineering and in that of steam engineering as well.

TEST OF LIFTING WATER FROM WELLS WITH AIR.

Presented by F. A. W. Davis, Vice-President Indianapolis Water Co.

June 4, 1898—11 A. M.

Size of well .... 10 inches
Depth of well . ... 330 feet
Depth of water above end of air pipe .... 64 feet, 4 inches
Outlet of Discharge pipe above water in well............. 25 feet, 8 inches
Lift.. .... 25 feet, 8 inches
Tank used—dimensions, length. .... 21 feet, 5 inches
" " width.............................. 5 feet
" " depth............. .... 2 feet, 6 inches
Capacity—cubic feet.. 267
" gallons 2,002.59
Length of air line in well including three feet of perforations 90 feet
Size of air line.. $2\frac{1}{2}$ inches
Air pressure on meter......................... .... 36 pounds
Meter used—Wilie Proportional Gas Meter................ 6 inches

First Test.

Time to fill tank. .... 2 min., $19\frac{1}{2}$ sec.
Cubic feet of air used.. 152
Air pressure on meter............. .... 36 pounds

Second Test.

Time to fill tank.. 2 min., 12 sec.
Cubic feet of air used.. 150
Air pressure on meter.. 36 pounds

Third Test.

Time to fill tank........... .... 2 min., 15 sec.
Cubic feet of air used.. 146
Air pressure on meter ... . 36 pounds

Fourth Test.

Time to fill tank.. 2 min., 21 sec.
Cubic feet of air used.. 140
Air pressure on meter .... 37 pounds

Fifth Test.

Length of air pipe.......67 feet
Depth of water above end of air pipe.......41 feet, 4 inches
Air pressure on meter.......46 pounds
Quantity of water required to fill tank.......2,002.59 gallons
Time to fill tank....... 2 min., 46 sec.
Cubic feet of air used....... 255

Sixth Test.

Time to fill tank....... 3 min., 35 sec.
Cubic feet of air used.......240
Air pressure on meter.......46 pounds

Seventh Test.

With longer pipe.

Length of air pipe.......110 feet
Depth of water over end of air pipe.......82 feet, 8 inches.
Outlet of discharge pipe above water in well.......27 feet, 4 inches
Air pressure on meter....... 44 pounds
Quantity of water required to fill tank....... 2,002.59 gallons
Time to fill tank....... 1 min., 53$\frac{2}{5}$ sec.
Cubic feet of air used.......100
Air pressure on meter.......44 pounds

Eighth Test.

Time to fill tank.......1 min., 50$\frac{1}{5}$ sec.
Cubic feet of air used.......101

Ninth Test.

With length of pipe further increased.

Length of air pipe....... 129 feet, 4 inches
Depth of water over end of air pipe.......102 feet, 2 inches
Outlet of discharge pipe above water in well.......27 feet, 2 inches
Air pressure on meter.......50 pounds
Time to fill tank.......1 min., 35 sec.
Cubic feet of air used.......100

Tenth Test.

Air pressure on meter.......43 pounds
Time to fill tank.......1 min., 45 sec.
Cubic feet of air used.......100

Eleventh Test.

Air pressure on meter.......43 pounds
Time to fill tank.......1 min., 43 sec.
Cubic feet of air used.......100

Twelfth Test.

Time to fill tank	1 min., 45 sec.
Cubic feet of air used	100

Thirteenth Test.

Air pressure on meter	44 pounds
Time to fill tank	1 min., 37 sec.
Cubic feet of air used	100

Fourteenth Test.

Air line	4 inches
Length of air line	111 feet, 1 inch
Depth of water over end of air pipe	83 feet, 7 inches
Outlet of discharge pipe above water in well	27 feet, 4 inches
Air pressure on meter	45 pounds
Time to fill tank	1 min., 55 sec.
Cubic feet of air used	105

Fifteenth Test.

Time to fill tank	1 min., 54 sec.
Air pressure on meter	45 pounds
Cubic feet of air used	107

Sixteenth Test.

Using curved nozzle deflecting air upwards 2½ inches.

Length of air line	108 feet
Depth of water over end of air pipe	80 feet, 8 inches
Water below discharge pipe	27 feet, 4 inches
Time to fill tank	1 min., 48 sec.
Air pressure on meter	43 ponnds
Cubic feet of air used	99

Seventeenth Test.

Air pressure on meter	46 pounds
Time to fill tank	1 min., 47 sec.
Cubic feet of air used	96
The tests show that the best results were obtained with of 2½-inch air line with three feet of perforations.	129 feet, 4 inches
Temperature at the discharge pipe of the compressor varied from	176 to 177 degrees
Average time in filling tank	1 min.. 44 sec.
" cubic feet of air used	100
" pressure on meter	44 pounds
The lift of water was	27 feet, 2 inches
The quantity of water discharged	2,002.59 gallons
Weight	15,576.66 pounds

The short pipe gave the poorest results. The test by the 4 inch pipe was to ascertain if, by reducing the annular space in the tenth, a greater flow of water would be obtained, but the results did not show it. In all of these tests the temperature varied only from one to two degrees at the compressors and at well. Temperature of water as it comes from well, 54 degrees.

The æration of the water causes it to precipitate the iron rapidly. The air line was covered to a depth of about one-sixteenth of an inch in eight months time.

The tests were made with care and it is hoped they will be of much value to the water works association. The members should bear in mind that the cubic feet is not free air, but compressed. The cooler the air is introduced into the well, so much the better. The contraction of the volume of air occurs when it comes in contact with the cold water and there decreases its effectiveness.

Heat units that will raise the temperature of one pound of water one degree will raise the temperature of one pound of air four degrees.

THE JUNE FIELD DAY OF THE ASSOCIATION.

Wednesday, June 6th, 1898, was the day named for the June outing of the Association. The morning came and it was one of those rare days in June when everybody delights to go afield. The trip as arranged was to include an inspection of the new water system of the city of New Bedford. A goodly number made the start from Park Square station in Boston, which was increased by additions at Mansfield, Taunton and other stations, so that on arriving at the Acushnet station, a few miles north of the city of New Bedford, about seventy-five persons took barges for a drive to the different points. Two or three miles over country roads brought the party to the new reservoir on a high hill in Dartmouth, having an elevation of about 216 feet above tidewater at the city. The reservoir is about 500 feet by 1,000 feet, holding about 65,000,000 gallons, and is divided into two sections, so that either section can be cleansed or repaired without cutting off the supply from the city. The reservoir was full at the time of the visit, having been filled by pumping back from the old supply, the new pumping works not being completed. The reservoir is an example of successful engineering and good workmanship, as no leak has manifested itself since its construction. A description of the works will be unnecessary in this sketch of a trip, as that was very pleasantly done by Mr. Edmund Wood in a paper published in the March number of the Journal for 1897.

Taking carriages again after a walk around the reservoir the party was conveyed to the Braley station on the N. Y., N. H. & H. Railroad, where the 48-inch force main crosses the tracks. Here a train of observation cars stood dumped on a side track. The dumps were soon righted and such planks and timbers as could be picked

up at the side of the track were extemporized as seats. And here we go, most of us standing, some astride the planks, with the engine pushing the train, over a track not the smoothest for passenger service, through the Bolton swamp and across the country, over the four or five miles of railroad which the city has constructed for carrying freight to their new pumping-station. Alongside this railroad is located the new 48-inch steel riveted force main, now all completed and covered in. A ride on a dump-car is not always the smoothest, but it is splendid for observation purposes.

Here on the southern shore of Little Quittacas pond, near the boundary line between Rochester and Lakeville, is located their new pumping-station. At the time of this visit the buildings were nearly completed and the tall circular chimney built of grey brick about 140 feet high was a conspicuous object for a long distance around. The combination of nature and art in the grounds and the buildings when completed will make this one of the prettiest spots imaginable. In the coal house was served a lunch to the hungry travelers. In the engine room workmen were busy getting in and setting up parts of the big pumps, which, when completed, will make this one of the finest plants in New England. Just at this time the workmen were about completing the excavations for the foundations for the gate-house. The work has not been carried along without more or less difficulty from quicksand.

Passing on foot half a mile, or so, along the shore of Little Quittacas, we came to the point where was being constructed the big conduit which is to connect the waters of Great Quittacas with Little Quittacas, across a public highway. The work here is not far advanced, but all was rush and stir. The combined area of the two ponds comprises about sixteen hundred acres, and they are expected to furnish a very fine quality of water. They are located in the towns of Middleboro, Lakeville and Rochester. The chain of lakes in this vicinity comprise an area of about six thousand acres, from one of which the city of Taunton takes its supply.

At the conduit the barges came up again and took the party to the northerly shore of the Great Quittacas, where a narrow strip of land separates this from Pocksha pond, which, further north, enlarges into Assawampsett. Over this strip or neck of land has always been a roadway. The New Bedford people have built this into a broad dam, with a gateway between the ponds; for the Legis-

lature has decreed that New Bedford may have the waters of the Quittacas ponds, and the surplus may flow into Pocksha, but the waters of Pocksha must not flow back into Quittacas. But a short time was spent here and the barges kept on some two or three miles to the Rock station in the town of Middleboro, where cars were taken for a return.

As the party alighted at the little country station they were taken by the good people of the village to be a party of men who had been prospecting the route of a proposed street railway from New Bedford to Middleboro, and it was so reported by the local news-gatherer in the local papers.

PROCEEDINGS

—OF—

THE SEVENTEENTH ANNUAL CONVENTION.

Portsmouth, N. H., September 14, 15, 16.

The headquarters of the Association during the convention were at the Hotel Wentworth, which is in the town of New Castle, about three miles from the railroad station in Portsmouth. The sessions of the convention were held in the hall of the hotel.

Wednesday, September 14, 1897.

The convention was called to order at 12 m., by President Kent.

The President introduced Mr. F. J. Philbrick, Chairman of the Board of Water Commissioners of the City of Portsmouth, who spoke as follows:

ADDRESS OF WELCOME BY MR. F. J. PHILBRICK, CHAIRMAN OF THE WATER BOARD.

Ladies and Gentlemen of the New England Water Works Association:

I have been requested by our Mayor, who is unavoidably detained (it is absolutely impossible for him to be present with you today, very much to his regret), to represent him on this occasion and extend to you all a hearty welcome to Portsmouth. You will find our latchstring out; we extend to you the freedom of the city. There are many places of interest here on account of their natural beauty and of their historic associations, and we hope you will all enjoy them as far as possible. We trust the meetings of your Association will result in great good in the dissemination of useful

knowledge relative to the business in which you are engaged—in which we are engaged—that of furnishing one of the vital necessities of human existence, an abundance of pure water. I am glad to see such an assembly of so many good looking people here in Portsmouth, who show the effect of cold water judiciously applied. (Laughter.) I trust you will have a profitable session, and that you will carry away with you pleasant recollections of our good old city by the sea. Our Superintendent has prepared a few data concerning our water system here, one of the most ancient in the country, and at some time during the course of your meetings he will have the pleasure of giving them to you. (Applause.)

RESPONSE BY PRESIDENT KENT.

I am sure, Mr. Philbrick, we shall appreciate it very much. In behalf of the New England Water Works Association I thank you for your cordial greeting. We consider ourselves very fortunate in the choice of the place for our present meeting. We meet for social intercourse and for the interchange of thought and experience on a topic which we believe to be of vital interest to every municipality, and we cordially invite all of your citizens who are interested in questions relating to public water supplies to be present at our sessions.

The first business in order is the consideration of applications for membership. The Secretary will read the list.

ELECTION OF NEW MEMBERS.

The Secretary presented the following list of applicants for membership, with the approval and recommendation of the Executive Committee :

RESIDENT ACTIVE.

Frank Baldwin French, Engineer and Superintendent of the Board of Public Works, Woburn, Mass.

NON-RESIDENT ACTIVE.

Edward L. Peene, Superintendent Water Works, Yonkers, N. Y.; Adolph W. Lautz, Secretary Pekin Water Works Co., Pekin, Ills.

The Secretary was directed to cast the vote of the Association in favor of the applicants which he did, and they were declared by the President elected to membership.

The President then delivered his annual address.

ADDRESS OF PRESIDENT KENT.

Gentlemen of the New England Water Works Association:

For the seventeenth time in its history, this Association has to-day assembled in annual convention. Its founders, twenty-seven in number, met at Salem on the twenty-first day of June, 1882, and laid the foundation on which our present organization has been erected—all honor to them, for they not only builded well at that time, but among them are numbered those who have ever been the most active participants in our meetings, and the most zealous in maintaining the integrity and promoting the welfare of our organization.

The most sanguine of its founders could hardly have anticipated the present strength and prosperity of the organization, enbracing, as it does, within its membership, representatives and specialists of every detail of the theoretical science, or the practical work of selecting, building and maintaining a perfect system of water supply.

From the nucleus of a membership of twenty-seven at date of organization in 1882, during the four years ending in 1886 the membership increased to 153 ; during the four years ending in 1890 the membership increased to 335 ; during the four years ending in 1894 the membership increased to 443 ; during the four years ending in 1898 the membership increased to 570 ; the present number on the rolls, an increase of twenty-one during the past year.

But the strength of our organization lies not so much in the number, as in the character of its membership, the practical value of the papers presented at its meetings and the transactions of the Association as published in its journal, an acknowledged authority on the subjects treated, and a publication of which any association might well be proud. Our financial condition continues prosperous, the treasury having a goodly balance to its credit.

On the death roll of the past year we have to record the name of William M. Hawes, a valued member of this Association. William M. Hawes will be long remembered as an active participant in our meetings, conspicuous for his genial disposition, his ready wit, his keen appreciation of the humorous, as well as for those more stering qualities of character which endeared him to all.

We have held the usual number of meetings during the year. The attendance at the monthly winter meetings has been remarkably uniform, the average being eighty-four and the minimum attendance seventy-five.

The annual field day was held in June, near New Bedford, where through the courtesy of members of the Association opportunity was afforded for the inspection of the detail of one of the largest and most thoroughly constructed plants for the purpose of water supply now in progress, an opportunity exceedingly instructive, which was fully enjoyed and duly appreciated.

Nineteen papers have been presented and discussed at the meetings of the Association during the past year, covering the following range of topics:

Two on the construction of water works systems.

Two on reservoir construction.

Two on pipe laying under rivers.

Two on backfilling trenches.

Two on meters.

One on service pipes.

One on service boxes.

One on loss of water from pipes.

One on handling air in a tube well plant.

One on operating a slow sand filter.

One on methods of obtaining water in the arid Southwest.

One on steel forgings.

One on sinking funds.

One on biology.

To further summarize, we have:

Five on general construction.

Five on special details of construction.

Four on special supplies.

Three on features of operating.

One on biology.

One on finance.

All as relating to water supply.

Of the several topics discussed, one of the most important, and one which is justly attracting much attention at the present time, is that of filtration. Comparatively few of our water works systems furnish water that is at all times, in all respects, everything that

could be desired, and the conscientious official is continually on the watch for improvement, but many are effectually debarred from improvement in this respect by the cost of construction and maintenance as exemplified by many of the filters in operation. It is obvious that in the selection of the source of a water supply no reasonable expense should be spared to obtain the best obtainable, so sufficiently good if possible as not to require any expensive system of filtration, and having acquired such a supply, to keep it free from pollution by proper legislation and proper enforcement of that legislation.

The expense of such a supply would probably be less in the end, and the results more satisfactory, than if obtained by filtration, for it is human nature to prefer water known to have been always free from contamination, rather than filtered sewage, no matter how perfect the system of filtration or how satisfactory the results.

For established plants where it is impracticable or impossible to remove the sources of contamination, and where other supply is not available, there is no other remedy; sooner or later they must filter their water regardless of expense, and the sooner the better; but for new works, expense within the limits of practicability should not stand in the way of securing a pure supply and keeping it so. We should unite in securing the most stringent legislation to prevent the pollution of water supplies and in maintaining and enforcing those regulations.

Of the many advantages to be derived from the interchange of thought and experience promoted by our organization, that by which the smaller works are enabled to profit by the experiences and experiments of those having larger means and facilities than are usually at the disposal of the smaller works, is one of the most important, and I fully appreciate the labor, care and fidelity which their representatives have devoted to the elucidation of methods in their various papers presented to the Association.

In conclusion, I congratulate you on the favorable surroundings of our present meeting, on your continued prosperity as an organization and urge you to manifest the same interest in the future meetings of the Association that you have in those of the past, to promote in every possible way its welfare, thereby enlarging its sphere of usefulness, that still greater success may be your portion.

The Treasurer then submitted his annual report as follows:

REPORT OF THE TREASURER.

George E. Batchelder, in Account With the New England Water Works Association.

Receipts.

1897.	Balance on hand as per last report:		
	People's Savings Bank.....................$	1,116.40	
	Safe Deposit and Trust Co.	1,377.48	
	City National Bank..........................	227.86	
			$ 2,721.74
Sept. 24.	Received from J. C. Whitney, Secretary.........$	750.00	
" 27.	" " " "	350.00	
1898.			
Feb. 10.	" " " "	700.00	
Mar. 14.	" " " "	250.00	
May 18.	" " " "	300.00	
June 13.	" " " "	550.00	
			$ 2,900.00
Aug. 1.	People's Savings Bank, interest................$	44.64	
Sept. 1.	Safe Deposit and Trust Co., interest...........	51.99	
" 1.	City National Bank, interest..................	5.50	
			$ 102.13
			$5,723.87

Expenditures.

1897.		
Aug. 26.	Newton Journal, printing programmes, circulars, etc..................................$	54.50
" 31.	W. T. Almy, badges...........................	13.20
Sept. 13.	Thomas P. Taylor, illustrating papers, and expenses at Newport................	18.72
" 16.	Bacon & Burpee, report of proceedings and expenses at Newport......	70 00
" 27.	Electro-Light-Engraving Co., eng. diagrams....	5.19
Oct. 15.	Boston Society of Civil Engineers, rent to October 15, 1897...	150.00
Nov. 15.	The Day Publishing Co., printing Sept. Journal.	255.80
" 22.	Electro-Light Engraving Co., engraving plans..	13.91
" 24.	W. H. Richards, salary to Sept. 1, 1897, postage, telegrams, telephone, etc................	89 15
" 27.	J. C. Whitney, salary to Sept. 1, 1897..........	125.00
Dec. 1.	" " " Dec. 1, "	125.00
" 11.	Electro-Light Engraving Co., engraving charts	11.83
" 24.	Newton Journal, printing letter heads, envelopes and circulars.	19.28
1898.		
Jan. 1.	The Day Publishing Co., printing Dec. Journal..	202.65
" 15.	W. H. Richards, salary to Dec. 1, 1897, express, postage, traveling expenses................	95.21
	Amount carried forward....................	$1,249.44

	Amount brought forward..........	$1,249.44	
Jan. 15.	Boston Society of Civil Engineers, rent to Jan. 15, 1898..........	100.00	
" 21.	Electro-Light Engraving Co., eng. diagrams....	4.03	
" 29.	" " " " " " ..	1.00	
Feb. 5.	J. C. Whitney, fares June meeting, telegrams, telephones, etc. as per vouchers....	146.31	
" 12.	W. E. Hassam, expenses to Feb. meeting.......	2.25	
" 23.	Chatterton-Warburton, floral pillow............	10.00	
Mar. 1.	Oliver Ditson Co, music at Feb. meeting.......	8.00	
" 1.	The Day Publishing Co., printing March Journal	145.55	
" 2.	Newton Journal, printing wrappers and circulars	21.50	
" 10.	Bacon & Burpee, report of winter meeting......	72.50	
" 26.	W. H. Richards, salary to March 1, 1898, traveling expenses, postage, etc.................	92.58	
May 31.	Newton Journal, printing postals, circulars, etc..	8.00	
June 1.	Electro-Light Engraving Co., merchandise......	13.94	
" 1.	J. S. Roberts & Son, express..................	.85	
" 4.	J. C. Whitney, salary to June 1, 1898.	250.00	
" 4.	" " postage, telegrams, express, as per vouchers..........................	55.13	
" 17.	W. H. Richards, salary to June 1, 1898, express, telegrams, postage, etc	91.84	
" 17.	The Day Publishing Co., printing June Journal..	364.03	
July 15.	Boston Society of Civil Engineers, rent to June 1, 1898..............	150.00	
			$ 2,786.95

BALANCE ON HAND.

Aug. 1.	People's Savings Bank......................	$ 1,161.04	
Sept. 1.	Safe Deposit and Trust Co.....................	1,429.47	
" 1.	City National Bank	346.41	
	Total Cash on Hand.....................		$ 2,936.92
			$ 5,723.87

Respectfully submitted,

GEORGE E. BATCHELDER, *Treasurer.*

REPORT OF THE FINANCE COMMITTEE.

In compliance with the by-laws of this Association, your committee has examined the books of the Treasurer and found the same to be correct. Respectfully submitted,

A. R. HATHAWAY,
A. W. F. BROWN, } *Finance Committee.*

September 13, 1898.

On motion of Mr. Hastings of Concord, N. H., the report of the Treasurer was received and placed on file.

On motion the report of the Finance Committee was received and placed on file.

The Secretary submitted the following report, which was received and placed on file :

REPORT OF THE SECRETARY.

Summary of Statistics Relative to Membership for Year Ending June 1,'98.

ACTIVE MEMBERS.

June 1, 1897, total active membership		464	
Withdrawals during the year		14	
		450	
INITIATIONS :			
September, 1897	20		
December, 1897	7		
January, 1898	2		
February, 1898	2		
March, 1898	7		
		38	
June 1, 1898, total active membership			488

HONORARY MEMBERS.

June 1, 1897, total honorary membership		5	
June 1, 1898, total honorary membership		—	5

ASSOCIATE MEMBERS.

June 1, 1897, total associate membership		80	
Withdrawals during the year		8	
		72	
INITIATIONS :			
September, 1897		5	
June 1, 1898, total associate membership			77
June 1, 1898, total membership			570

A gain for the year of 21.

Summary of Receipts for the Year Ending June 1, 1898.

DR.

Received for annual dues	$1,485.00
" advertisements	1,168.00
" initiations	120.00
" Journals	122.00
" miscellaneous	5.00
	$2,900.00

Cr.

Sept. 24, 1897.	Paid Geo. E. Batchelder, Treasurer...	$	750.00
Dec. 23, 1897.	" "		350.00
Feb. 10, 1898.	" "		700.00
Mch. 12, 1898.	" "		250.00
May 17, 1898.	" "		300.00
June 12, 1898.	" "		550.00
		$	2,900.00

The President announced that since the close of the year, in June, the Association had lost by death another member, Mr. Wilbur D. Fiske of Boston, who was an active member of the Association and an active participant in its meetings.

AFTERNOON SESSION.

At the afternoon session Frederick S. Hollis, Biologist, Metropolitan Water Board, Boston, read a paper entitled : "Method for Determination of Color and the Relations of the Color to the Character of the Water."

The discussion was participated in by Messrs. Whitney, Haskell, Fuller, Chase and Bancroft.

EVENING SESSION.

At the evening session William R. Hill, Chief Engineer and Superintendent, Syracuse, N. Y., read a paper entitled : "Some Things that Should be Done in Constructing a Distributing System of Water Works."

The paper was discussed by Messrs. Chase, Whitney, Hawley, Fuller, Haskell, Crandall of Burlington, Walker, Hyde, Thomas of Hingham, Coffin and Richards.

The President presented to the Association Mr. John O. Ayres, saying : As we visit different New England cities, we meet with many peculiar features of water works construction and management. One of the most peculiar, and one which I think will be appreciated by the superintendents present, is met with here in the city of Portsmouth, in the circumstance that for nearly one hundred years the works have had but three superintendents. I have the pleasure of presenting to you Mr. John O. Ayers, who has been connected with these works for the past thirty years. (Applause.)

REMARKS OF SUPERINTENDENT AYRES.

Mr. President, and Gentlemen of the Association :

I have been requested by your Secretary to give you a little informal talk about the Portsmouth water works. The works were chartered in 1797, and were built in 1798. The construction would be considered rather crude today, but still it answered very well for the purpose. They used what they called pump-logs cut in lengths of from 14 to 16 feet, with a bore 5 inches in diameter, and hooped at each end. To connect them they used oak tubes, which were turned to taper at each end and were then inserted in the logs and the logs driven together. The cost of the first main laid in 1798 was approximately $7,000. The Company had at first 127 water-takers and received from them in 1798 $638. In 1800, the number of water-takers had increased only 15, making 142 water-takers, paying $710. In 1805. they had increased to 245, paying $1,325; in 1810, they had increased only 20, to 265, and increased the revenue $50, paying $1,375; in 1820, only 20 more had been added, there being 285 takers, paying $1,400; in 1830, they had increased to 340, paying $2,000; in 1840, there had been an increase of takers up to 459, paying $2,800; in 1850, they had increased to 700, paying $5,000; in 1860, they had increased 400 to 1,100, paying $6,500, an increase of $1,500 in the last ten years; in 1870 they had increased to 1,400 takers, paying $18,000; in 1880, to 1,700 takers, paying $19,000; and in 1890, the last year of the existence of the old corporation under the name of the "Proprietors of the Portsmouth Aqueduct," the number of takers had increased to 1,900 and the water rates amounted to $23,000.

In 1808–9, some ten years after the first construction, a second main of the same character, old pump logs, was laid from the same source of supply, which was springs not over 4 feet deep, and from which the water has flowed ever since and is now flowing to our pumps from the same spot at the rate of three or four hundred thousand gallons a day. Those springs supplied the city directly, without any expense of consequence, until 1850, when a distributing reservoir was built holding 500,000 gallons.

Perhaps it will be well enough to say here, before I go any further, that the demand for water in those days was simply in the

cellars of the houses. A good many of the service pipes were wood logs of an inch and a half bore. Lead was costly, probably, I think it was imported from England, and consequently wood services were used.

In 1850 this distributing reservoir was built. The increase in the revenue from 1840 to 1850 was owing largely to the establishment of the breweries, some of the takers using at least 250,000 gallons a day, and the small works were taxed sometimes pretty severely to supply the demand and to keep up what little head there was, for the pressure was light.

My father was superintendent of the work for nearly fifty years, and I grew up as a boy with the works and have been acquainted with them from the time I was big enough to know anything, being around and about them all the time, and particularly in the summer when any work was done I was very apt to be on hand and to see what was going on.

In 1890, the works were sold to the City of Portsmouth, to be delivered on the 1st of January, 1891. Commissioners were appointed under the bill granting the city the right to purchase, the works were taken and the city proceeded to construct a modern system, using, however, the same sources of supply that the old company had acquired and had used. Between 1860 and 1890 the company had added three sources of supply, one some miles to the north of the original source, one about three-quarters of a mile to the south, and another about half a mile to the east, each having a different elevation. In 1875, in the locality at the north we put down two 8-inch driven wells that have proved very successful. One is 70 feet deep and one 60 feet deep. The two are within 250 feet of each other, and from each of them I think there could be easily pumped a million gallons a day, any day in the year. We simply use them now in extreme drouth in summer. Some years we do not have to use them at all. We have an auxiliary pump located there. The city, after buying the works, built a pumping station and concentrated all these different supplies of water at the lowest point, and put in a 2,000,000 Deane pump, and an auxiliary 1,000,000 Deane pump. Last year they changed and put in a 3,000,000 gallon Worthington. The demand for water this summer has been very large, although some of our largest takers are partially supplying themselves with water from their own works. The largest

day's pumpage was 1,800,000 gallons, and I think we have averaged 1,350,000 gallons a day since the first day of June.

Perhaps you may be interested to know of some of the troubles we experienced with the old pump logs. As late as in the sixties one of the mains was not furnishing nearly as much water as the adjoining one. After considerable search we discovered that a tree some 30 feet away had thrown out its roots and the fibers had grown through the thinnest part of the log near the point, and had filled it, for 5 feet in length, nearly solid full, stopping it up almost completely. The durability of the old logs under the pressure we had was somewhat astonishing, the last three of those laid in 1798 being taken up in the seventies. Instead of being 5-inch bore they were 8, with the knots protruding in all directions, the knots not having worn away as fast as the soft wood, and being as fine and smooth as polished mahogany. If any of you have questions to ask which I can answer I shall be pleased to do so.

Mr. Holden. What pressure was on the old logs?

Mr. Ayres. Until 1860, there was about 24 pounds pressure. Logs, as we all know, would be good for nothing except under light pressure. We used some Wyckoff patent pipe under 35 pounds pressure from the springs we added in 1875, and it answered very well, except through a clay swamp, where we found it almost worthless, as the bands were eaten off very quickly. But after 15 years of use we could see no deterioration in the pipe which was laid through gravel.

Mr. Fuller. How were the joints for the service pipe made?

Mr. Ayers. The joints for the service pipes, after we commenced to use lead, were simply bored, and the lead pipe pushed in and wedged with dry, clear pine.

Mr. Fuller. A short piece of lead pipe connecting the main with the wooden service pipe?

Mr. Ayers. Yes, when we used wooden services. We have used all kinds of services, and perhaps some kinds that some of you gentlemen have never seen. At one time for people who could afford it and were somewhat afraid of lead and wanted something different, we put in what was called glass-lined pipe, manufactured by a party in Boston. This was a cast-iron pipe an inch and a half in diameter, through which was run a glass tube about half an inch

thick, and between that and the iron pipe it was filled in with calcine. Then, later, parties wanting a glass pipe purchased what they called a glass enamelled pipe made in England, a $\frac{3}{4}$-inch pipe costing 57 cents a foot, and 1-inch pipe costing some 70 cents, I think. That was simply an enamel of glass inside and out on a wrought-iron pipe. The first pipe I spoke of, the cast-iron lined with glass, cost 50 cents a foot in those days. Some of the older people, however, would never have anything but wood.

Mr. Bisbee. Was this wrought-iron pipe threaded, did it have a thread on, or was it put together with lead joints?

Mr. Ayres. The first I named was put together with lead joints. It was a perfect pipe, as far as carrying the water was concerned, if they kept the frost out of the cellars. I never knew but one to freeze, and that was in one of our best houses. The weather was very cold, below zero, and the parties left the big cellar door some four feet from the pipe open over night, and in the morning they had no water. Complaint was made that they couldn't get any water, and that there must be some trouble with the works. The water froze in some 4 or 5 feet of pipe and the glass was shivered in all shapes.

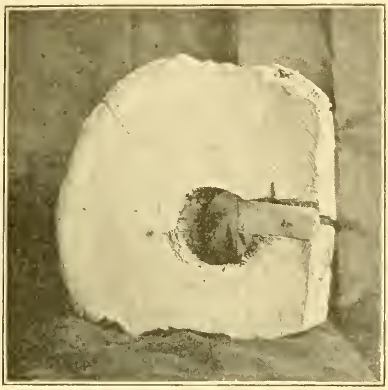
Mr. Fuller. I suppose there were no hydrants connected with the old mains?

Mr. Ayres. All the fire protection was from reservoirs, which the old company filled for the city free of cost. They never charged the city for water for fire purposes or for school-houses. Perhaps I might say further that there were very few years but what the old company paid a dividend. I should like to show you the old record book of 1798, for I think the handwriting of the old fellow, who has passed on, and some of the entries he made, might interest you.

The President. Is there any of the old log pipe in existence at the present time?

Mr. Ayers. None that I know of. I should be pleased to see any of you in my office before you go back, or all of you who can get in there. (Applause.)

On motion of Mr. Hill the thanks of the Association were extended to Mr. Ayers.



SECTION OF WATER LOG.

This log or wooden water pipe was a part of the Boston Aqueduct laid in 1836, and was taken from under the house of Wendell Phillips in Essex Street. This illustration is from a piece presented to Mr. Henry F. Jenks by the Ashton Valve Co.

THURSDAY, September 15.

The convention met at 10.20.

The Secretary read the following names of applicants for membership, the applications having been approved by the Executive Committee:

RESIDENT-ACTIVE.

P. D. O'Connell, Superintendent, Somersworth, N. H.; A. H. Burse, Superintendent, Pittsfield, Maine.

On motion of Mr. Crandall of Burlington, the Secretary was directed to cast the ballot of the Association for the applicants, which he did, and they were declared elected.

Mr. Stacy moved the appointment by the chair of a committee of five to make nominations of officers for the ensuing year. The motion was adopted and the chair appointed the following as the committee: Messrs. Stacy, Kieran, Codd, Holden and Cook of Woonsocket.

AMENDMENT OF THE CONSTITUTION AS TO PLACE OF MEETING.

THE SECRETARY. There is a report of the Executive Committee of the Association containing a recommendation for an amendment

to the constitution. The amendment suggested is in Section 3 of Article VII, which now reads as follows: "The place for holding the regular meetings of the Association shall be decided by vote of the members, but no regular meeting shall be holden outside the New England States." The amendment recommended is that the clause "but no regular meeting shall be holden outside the New England States" be stricken out.

MR. RICHARDS. I would like to have the Secretary read the section of the constitution which states how an amendment shall be made.

THE SECRETARY. It is Section 3 of Article VIII. which provides: "All propositions for adding to or altering any provisions of the foregoing constitution shall be submitted to the Executive Committee who may bring the matter before the Association; and they shall bring before the Association any proposed amendment having the written endorsement of ten members. A two-thirds affirmative vote of the members present and voting shall be necessary for the adoption of such amendment."

MR. THOMAS of Lowell. I move that the matter lay on the table until our meeting tomorrow forenoon, and meanwhile the members can be notified of it, and we will probably have a better attendance then than we have now.

Mr. Thomas' motion was adopted.

Mr. Robert S. Weston of Brockton, Mass., read a paper entitled, "The Occurrence of Cristatella in the Storage Reservoir at Henderson, North Carolina."

The paper was discussed by Messrs. Haskell, Hollis and Chase.

Mr. Frank L. Fuller of Boston gave a description of the Monson, Mass., water works, after which the convention adjourned till evening.

EVENING SESSION.

Mr. Henry F. Jenks, who had charge of the exhibit of water works appliances, made the following report:

Hayden & Derbey, Mfg. Co., New York., Metropolitan Injectors and Ejectors.

Builders' Iron Foundry, Providence, Service Box, Pamphlets of Venturi Meters and Globe Specials.

Coffin Valve Co., Boston, Fire Hydrant Gates, Check Valves, Sluice and Sewer Gates.

Fred W. Gow, Medford, Improved Apparatus for Testing Meters.

Hersey Mfg. Co., Boston, Meters.

Union Water Meter Co., Worcester, Pressure Regulators and Meters.

H. Mueller Mfg. Co., Decatur, Ill., Tapping Machines, Regulators and Water Works Supplies.

Lead Lined Iron Pipe Co., Wakefield, Lead Lined Iron Pipe and Fittings.

Henry F. Jenks, Pawtucket, Street and Park Drinking Fountains.

A. P. Smith Mfg. Co., Newark, N. J., Sherly Tapping Machine, Lead Pot Fused with Kerosene Oil, and General Water Works Supplies.

Ashcroft Mfg. Co., New York, Steam, Vacuum and Water Pressure Gauges, Indicators and Recording Gauges.

Rensselaer Mfg. Co., Troy, N, Y., Valve, Gates, and Gate Boxes and Corey Fire Hydrants.

Chapman Valve Co., Boston, Valves and Hydrants.

National Meter Co., New York, Meters.

Neptune Meter Co., New York, Meters.

Ross Valve Co., Troy, N. Y., Valves, Water Engines and Filters.

Thompson Meter Co., Brooklyn, N. Y., Meters.

Consolidated Safety Valve Co., New York, Pop Safety Valves and Water Relief Valves.

Dr. Gardner T. Swarts, secretary of the Rhode Island State Board of Health, read a paper entitled: "Man's Imitation of Nature in Purification of Water."

Following the reading of the paper Mr. Robert S. Weston spoke on the subject of the removal of bacteria and suspended matter in river waters by sedimentation, and gave some facts in regard to the proposed filter plant at Louisville. Subjects considered in the paper were also discussed by Mr. Clark and Mr. Thomas of Hingham.

Mr. George Bowers, city engineer of Lowell, Mass., next read a paper in which he gave the results of tube well experiments in Lowell.

FRIDAY, September 16.

Robert W. Taber, member of the water board of New Bedford, and Washington Paulison, superintendent water company Passaic, New Jersey, were elected active members of the Association.

Mr. John C. Haskell of Lynn, Mass., read a paper on "Surface Water Supplies."

The paper was discussed by Messrs. Clark, Richards and Fels.

A paper, written by Edmund B. Weston, consulting engineer, Providence, R. I., describing the separate high pressure fire service in that city, was read by Mr. French.

A communication was received from Mr. F. A. W. Davis, vice-president and treasurer of the Indianapolis Water Company, enclosing a quotation from the report of the duty test of the Company's new engine, made by Prof. Goss, of Purdue University.

CONSTITUTION AMENDED

The report of the Executive Committee recommending an amendment to the constitution by striking out the clause in section three of article seven, "but no regular meeting shall be holden outside the New England States," was taken from the table.

Mr. Stacy moved that the recommendation be adopted and that the constitution be so amended.

In answer to a question by Mr. Thomas of Hingham as to what per cent of the members live in the New England States, the Secretary said about 80 per cent.

Mr. Stacy. I am in favor of this amendment, for I think this Association is competent to determine for itself where it wants to hold its meetings. I think it is unnecessary that we should have a prohibitory law in the New England Water Works Association, and if we want to visit California, or the Rocky Mountains, or Chelsea, we have intelligence enough to vote as to where we want to go, and the majority will rule here as in all other organizations.

The motion was adopted.

Mr. Stacy. I now have a pleasant duty to perform, which has been entrusted to my unworthy care by a gentleman who is himself too modest to state the generous and cordial invitation which he wishes to extend to this Association ; and it becomes in order now, since this motion has been adopted by the Association and we are at liberty to hold our meetings where we see fit. I have been requested by Mr. Hill to invite you to hold your next annual meeting in Syracuse. It has been some time since we have had an invitation to meet in any particular place, and it seems to me that an invitation of this kind should have very serious consideration by the members. From the knowledge we have of what the citizens of Syracuse, backing up Mr. Hill, did almost on the spur of the moment for another association which met a few miles from there, we are promised a reception by the citizens, such as almost makes us blush, modest as we are. If we seriously contemplate any excursion of that kind,

we should have due warning so we can have plenty of training to get ready for it. This invitation comes to us spontaneously, a great, generous invitation to visit Syracuse, with a guarantee that we will be royally entertained, a guarantee which is backed up by the experience of others who have been there, and an invitation given not only by one little body of men, but by the leading citizens of the place, who take an honest pride in the growth of the city and who want the whole world to come and see what they have done. They claim, as we all claim, to have the best water works in the country—I wouldn't give a cent for a man who didn't claim that—and they want us to see it. We know if we were going anywhere near Syracuse, from what we have seen in the papers and from the descriptions we have read by prominent engineers of what has been done there, we would all make an effort to visit the city, being sure of learning something there which would be of advantage to us.

This Association has never yet been out of New England. When sometimes a proposition has been made to go more than 50 miles from Boston, we have been scared most to death. Some of us were afraid when we decided to go to Burlington that we wouldn't have any sort of an attendance there, but we found we did have a good attendance, and we had a splendid time, and I think if we had even gone clear across the line we would have gone in good numbers. The American Association, who are our rivals in one sense in promulgating knowledge on water works matters to the people, go all over the United States, yet we have just been paddling about around in New England all the time, while beating them in almost everything else. Now it seems to me if we go to Syracuse, we will be near Niagara Falls, and near the Thousand Islands, and we could see a good deal more even than we could in Lynn, and we saw a good deal in Lynn. (Laughter and applause.) I think a change of scene will do us good. It won't do us any harm to get out of New England and knock a little rust off us by rubbing up against some other people.

I am glad this invitation has come at this time so that we can thoroughly consider it. We are not obliged to settle it today, and I hope to see, with a membership of over 500 in the Association, great enthusiasm in carrying out what is for the best interests of the Association. And I think, if we can work up properly this trip to

Syracuse, we will have one of the largest and most interesting meetings we have ever had, with lots of visitors, and lots of men who are interested in exhibiting to us what is new in the way of water works supplies, and in telling us what is going on. We have a pretty little exhibit here, but it is only a small sample of what we ought to have. There is one thing I want to impress upon you, and that is the heartiness of this invitation, the ocean of generosity which is behind it, and the anxiety of the citizens of Syracuse to back it up and to show us what they have got and what nice people they are.

THE PRESIDENT. The invitation is certainly very cordial and generous, and it will be referred to the Executive Committee to be reported upon at the first winter meeting of the Association.

ELECTION OF OFFICERS.

Mr. Stacy, chairman of the committee appointed to nominate officers for the ensuing year, presented the following report:

PRESIDENT.

F. F. FORBES, Superintendent, Brookline, Mass.

VICE-PRESIDENTS.

MELVILLE A. SINCLAIR, Superintendent, Bangor, Me.; CHARLES K. WALKER, Superintendent, Manchester, N. H.; F. H. CRANDALL, Superintendent, Burlington, Vt.; BYRON I. COOK, Superintendent, Woonsocket, R. I.; ROBERT J. THOMAS, Superintendent, Lowell, Mass.; R. S. BARTLETT, Superintendent, Norwich, Conn.

SECRETARY.

JOHN C. WHITNEY, Commissioner, Newton, Mass.

TREASURER.

GEORGE E. BATCHELDER, Water Registrar, Worcester, Mass.

SENIOR EDITOR.

JOSEPH E. BEALS, Superintendent, Middleboro, Mass.

JUNIOR EDITOR.

WALTER H. RICHARDS, Superintendent, New London, Conn.

EXECUTIVE COMMITTEE.

PATRICK KIERAN, Superintendent, Fall River, Mass.
JOHN C. HASKELL, Superintendent, Lynn, Mass.
GEORGE A. STACY, Superintendent, Marlborough, Mass.

FINANCE COMMITTEE.

WILLIAM F. CODD, Superintendent, Nantucket, Mass.
ARTHUR W. F. BROWN, Registrar, Fitchburg, Mass.
HORACE KINGMAN, Superintendent, Brockton, Mass.

On motion of Mr. Chace, the report of the nominating committee was accepted, and the Secretary of the Association was directed to cast one ballot in favor of the nominees, which he did, and they were declared elected.

On motion of Mr. Richards, the thanks of the Association were tendered to the retiring President, Mr. Kent, and to the Secretary.

Adjourned.

Attendance at 1898 Convention of the New England Water Works Association held at Portsmouth, N. H., September 14th, 15th and 16th.

ACTIVE MEMBERS.

Willard Kent, Narragansett Pier, R. I.; R. J. Thomas, Lowell, Mass.; Edw. L. Peene, Yonkers, N. Y.; Lewis M. Bancroft, Reading, Mass.; Fred W. Gow, Medford, Mass.; Albert S. Glover, Boston, Mass.; A. W. F. Brown, Fitchburg, Mass.; J. C. Whitney, Newton, Mass.; Charles S. Warde, Staten Island, N. Y.; George E. Batchelder, Worcester, Mass.: Joseph E. Beals, Middleboro, Mass.; Wm. F. Codd, Nantucket, Mass.; A. H. Salisbury, Lawrence, Mass.; F. E. Bisbee, Auburn, Me.; Chas. H. Baldwin, Boston, Mass.; W. G. Zick, New York, N. Y.; J. C. Sullivan, Holyoke, Mass.; C. D. Colson, Holyoke, Mass.; J. L. Tighe, Holyoke, Mass.; James Burnie, Biddeford, Me.; F. S. Hollis, Boston, Mass.; G. W. Harrington, Wakefield, Mass.; F. L. Northrop, Boston, Mass.; W. C. Hawley, Atlantic City, N. J.; P. D. O'Connell, Somersworth, N. H.; Daniel B. McCarthy. Waterford, N. Y.; W. R. Hill, Syracuse, N. Y.; V. C. Hastings, Concord, N. H.; James A. Huntington, Haverhill, Mass.; J. Waldo Smith, Paterson, N. J.; W. Paulison, Passaic, N. J.; Frank A. Andrews, Nashua, N. H.; J. F. Gleason, Quincy, Mass ; W. W. Ewell, Quincy, Mass.; F. H. Crandall, Burlington, Vt.; Patrick Kieran, Fall River, Mass.; D. N. Tower, Cohasset, Mass.; Wm. H. Thomas, Hingham, Mass.; Freeman C. Coffin, Boston, Mass.; George F. Chace, Taunton, Mass.; Henry A. Cook, Salem, Mass.; George K. Crandall, New London, Conn., L. E. Daboll, New London, Conn.; Byron I. Cook, Woonsocket, R. I.; W. H. Richards, New London, Conn.; Thomas C. Gleason, Ware, Mass.; X. H. Goodnough, Boston, Mass.; H. N. Hyde, Newton, Mass.; F L. Fuller, Wellesley, Mass.; George Bowers, Lowell, Mass.; Robert S. Weston, Brockton, Mass.; M. A. Sinclair, Bangor, Me.; H. T. Sparks, Bangor, Me.; George A. Stacy, Marlboro, Mass.; James F. Bigelow, Marlboro, Mass.; George E. Crowell, Brattleboro, Vt.; H. G. Holden, Nashua, N. H.; A. H. Burse, Pittsfield, Me.; D. H. Gilderson, Haverhill, Mass.; George E. Winslow, Waltham, Mass.; J. W. Crawford, Lowell, Mass.; John C. Haskell. Lynn, Mass.; Frank E. Merrill, Somerville, Mass.; C. E. Chandler, Norwich, Conn.; H. W. Clark, Boston, Mass.; E. V. French, Boston, Mass.; Daniel Russell, Everett, Mass.; Louis E. Hawes, Boston, Mass.

HONORARY MEMBERS.

"Engineering News," by Samuel B. Read and M. N. Baker; "Engineering Record," by Henry C. Meyer and G. H. Partridge; "Fire and Water," by F. W. Sheppard.

Associate Members.

Ashcroft Mfg. Co., by Frank Andrews.
Builders' Iron Foundry, by S. C. Clifford.
Chapman Valve Co., by E. L. Ross.
Deane Steam Pump Co., by Charles P. Deane and Allen M. Pierce.
Hersey Mfg. Co., by James A. Tilden, F. B. Smith, A. A. Blossom.
Jenks, Henry F., Pawtucket, R. I.
Ludlow Valve Mfg. Co., by H. F. Gould.
Lead Lined Pipe Co., by T. E. Dwyer.
Mueller Mfg. Co., by F. B. Mueller, M. G. Millikin.
National Meter Co., by John C. Kelley, W. P. Oliver, J. G. Lufkin.
Neptune Meter Co., by H. H. Kinsey.
Rensselaer Mfg. Co., by Fred S. Bates.
Ross Valve Co., by William Ross.
Smith A. P. Mfg. Co., by W. H. Van Winkle.
Thomson Meter Co., by Henry Folger, S. D. Higley.
Worthington, H. R., by J. M. Betton.

Guests.

Mrs. Lewis M. Bancroft, Reading, Mass.; Miss Mabel E. Bancroft, Reading, Mass.; Mrs. E. L. Ross, Indian Orchard, Mass.; Mrs. W. H. Van Winkle, Newark, N. J.; Mrs. Joseph E. Beals, Middleboro, Mass.; Mrs. J. P. Bacon, Cambridge, Mass.; Mrs. James A. Tilden, Boston, Mass.; Miss B. F. Whitaker, Boston, Mass.; Mrs. G. W. Harrington, Wakefield, Mass.; Mrs. J. F. Gleason, Quincy, Mass.; Mrs. W. W. Ewell, Quincy, Mass.; Mrs. George K. Crandall, New London, Conn.; Mrs. L. E. Daboll, New London, Conn.; Mrs. George Bowers, Lowell, Mass.; Mrs. H. G. Holden, Nashua, N. H.; Mrs. William H. Thomas, Hingham, Mass.; Mrs. D. N. Tower, Cohasset, Mass.; Mrs. George F. Chace, Taunton, Mass.; Mrs. C. A. Kent, Narragansett Pier, R. I.; James P. Bacon, Cambridge, Mass.; W. H. Lawrence, Newburyport, Mass.; Joseph W. Milne, Fall River, Mass.; Julian P. Wood, Marlboro, Mass.; William E. Hill, Salem, Mass.; C. H. Danforth, Salem, Mass.; Edward E. Brown, Salem, Mass.; F. L. Weaver, Lowell, Mass.; August Fels, Lowell, Mass.; M. J. Dowd, Lowell, Mass.; S. B. Palmer, Norwich, Conn.

NEW ENGLAND WATER WORKS ASSOCIATION.

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This Association, as a body, is not responsible for the statements or opinions of any of its members.

SURFACE WATER SUPPLIES OF MASSACHUSETTS.

BY JOHN C. HASKELL, SUPT., LYNN, MASS.

[*Read Sept. 16, 1898.*]

Mr. President and Members of the Association:

Although doubtless all present are thoroughly conversant with the character of the water contained in the ponds and streams of your own water systems, you do not all fully realize the character of the water in its entirety throughout the State of Massachusetts. The result desired to be attained in constructing a water system for a city or town, is to secure an abundance of good, potable water at all times fit for domestic purposes, that is, not dangerous to health, or offensive to taste, possessing no odors, and with so little color as not to be readily perceptible when you fill a goblet to quench your thirst.

These requisite qualities seem ones to be easily secured, and it is often claimed by those in charge of our public water supplies, that in fact, in their particular case, they are secured, being the best without exception in the entire country, or one of the best. Any reflection on the character of the water is promptly shown to be a mistake, or is explained by the person consulted, as possibly a local trouble that may be easily remedied at once, or that it will improve from natural causes in a short period of time.

If asked to answer the question, are the surface water supplies of the State, as a whole or individually, capable of furnishing at all times a satisfactory water for domestic use, I should reply without

any doubt that collectively they are not the ideal water to be desired or that might be secured. I will endeavor to present to you some of the reasons on which I base the answer.

We will first consider the dangerous quality as represented by the typhoid germ, the colan bacillus, the most dangerous of all organisms to be feared, but which unfortunately is so minute as to render it impossible of discovery by any examination to which the water is submitted. It neither affects the odor or taste of the water; the fact of its presence in any large numbers is first suspected by the unusual prevalence of the typhoid fever in a community and after an investigation by an expert, the source of infection is found to have been in the water supply. It is generally understood that the typhoid germ can only be present in the water from having been contributed by an actual case of typhoid fever existing within the watershed and which through either ignorance or carelessness is allowed to contaminate the water. In the past, so many epidemics of typhoid fever have been traced to this source that you are all well aware that this source of danger is ever liable to make its presence known in any water supply that is contaminated with sewage. That even an inmate of a family residing in the vicinity of a small stream miles away from the pond or storage reservoir, can thoroughly infect the water of the largest pond; that the presence of a picnic party on the banks of one of the streams is a possible cause of infection. We also have reason to believe that its deadly work is apparent even when not sufficiently frequent to be entitled an epidemic, but can only be suspected from a death rate from typhoid fever in excess of previous years or greater than is to be found in other cities similarly situated.

We will now consider the disagreeable qualities present in the water. To absolutely show to you the character of the water contained in our different supplies, it would be necessary to classify the effect produced upon the water from the presence of each of the 96 different organisms present during the year of 1896 as found by the microscopical examinations of the waters of the State, conducted monthly by the State Board of Health. I will not attempt to make the classification for lack of time, but will assume that the presence of 400 organisms per cubic centimeter will cause the character of the water to be unsatisfactory for domestic use. We find upon an examination of the number of organisms found to be

present in the waters of the various ponds, reservoirs, streams and taps of the surface water supplies of the State during the year of 1896 (when less than twelve examinations were made the result is expressed in twelfths) that applying the standard of 400 organisms per cubic centimetre the water was found to be unsatisfactory in one sample of water in every examination; in one, in 11 of the 12; in two, 10 of the 12; in one 9 of the 12; in three, 8 of the 12; in one, 7 of the 12; in two, 6 of the 12; in three, 5 of the 12; in twelve, 4 of the 12; in seven, 3 of the 12; in eleven, 2 of the 12; in nine, 1 of the 12; in twelve, less than 400. In all of the examinations we find that the water as determined by the analysis and standard taken, would be considered as unsatisfactory for one quarter of the year. To still further show the character of the water and that water containing 400 organisms per cubic centimeter would properly be classified as unsatisfactory, I will present the expressed opinion of the expert who conducted the monthly microscopical examinations for the State Board of Health at the time of making the examinations of the waters of one of the ponds mentioned previously, the waters in which had a general average for the year of 173 organisms per cubic centimeter.

Odor, January cold, none, hot, faintly vegetable; February, cold, none, hot, faintly vegetable; March, cold, faintly vegetable, hot, faintly vegetable; April, cold, faintly vegetable; hot, faintly vegetable; May, cold, distinctly grassy, hot, decidedly mouldy and grassy; June, cold, faintly vegetable, hot, distinctly vegetable; July, cold, faintly vegetable, hot distinctly vegetable; August, cold, distinctly vegetable, hot, distinctly vegetable; September, cold, faintly vegetable, hot, faintly vegetable; October, cold, faintly vegetable, hot, distinctly sweetish; November, cold, none, hot, very faintly vegetable; December, cold, none, hot, none. Of another pond which contained less than 400 organisms per cubic centimeter, at each examination his expressed opinion of the quality is still more forcible. January, cold, distinctly vegetable, hot, distinctly vegetable and mouldy; February, cold, distinctly vegetable, hot, distinctly vegetable and mouldy; March, cold, distinctly vegetable, and mouldy, hot, distinctly vegetable and mouldy; April, cold, vegetable and mouldy, hot, distinctly vegetable and mouldy; May, cold, distinctly vegetable and mouldy, hot, distinctly vegetable and mouldy; June, cold, distinctly vegetable, hot, distinctly

vegetable, and mouldy; July, cold, distinctly vegetable, hot distinctly vegetable and mouldy; August, cold, distinctly vegetable and unpleasant, hot, decidedly mouldy and barnyard; September, cold, distinctly mouldy, hot, decidedly mouldy and barnyard; October, cold, decidedly mouldy, hot, decidedly mouldy; November, cold, distinctly vegetable and mouldy; December, cold, distinctly vegetable, hot decidedly vegetable and astringent.

Of another pond in which the water contained an excess of 400 organisms in ten of the twelve examinations, his expressed opinion is as follows: January, cold, distinctly pleasant, hot, distinctly pleasant and sweet; February, cold, distinctly vegetable, hot, distinctly vegetable and sweetish; March, cold, faintly vegetable, hot, distinctly vegetable and sweetish; April, cold, faintly vegetable, hot distinctly vegetable; May, cold, distinctly grassy and unpleasant, hot, distinctly grassy; June, cold, distinctly grassy and disagreeable, hot, distinctly vegetable; July, cold, decidedly grassy and mouldy, hot, very decided sweet corn odor, ; August, cold, decidedly vegetable and grassy, hot, decidedly vegetable, sweet and grassy; September, cold, distinctly grassy and sweetish, hot, decidedly sweet and grassy; October, cold, distinctly vegetable and grassy, hot, decidedly sweet; November, faintly pleasant, hot, distinctly pleasant; December, cold, faintly vegetable, hot distinctly sweetish.

We find upon comparison of the surface waters of the State when judged by the standard of 400 organisms per cubic centimeter that the unsatisfactory water is present one-quarter of the time. When judged by the odor test as applied to two of the ponds previously classed as containing good water, the unsatisfactory odor was present in forty-three of the forty-eight examinations and in the pond in which the organisms exceeded 400 per cubic centimeter, in ten of the twelve examinations the odor test was unsatisfactory in the twenty-four entire tests. Should further proof be required that the surface water supplies of the State, supply water unsatisfactory to many of the takers it may be found in the thriving business done in most of our cities by parties furnishing spring water to the water takers and also in the great number of filters in use on the taps.

The work of our State Board of Health from year to year has demonstrated without question that in the ponds and streams of our various surface water supplies there lurks an insidious danger which

is not possible to be discovered until the unusual death rate from typhoid fever makes its presence plainly apparent, also that no pond or storage reservoir now in use as a public water supply can at all times furnish water of good character such as is proper to be used for domestic use. We find, however, that fully appreciating the dangers inherent in surface water supplies the most careful study has been made by the State Board of Health of the best methods by which the dangerous and disagreeable qualities of the water can be eliminated. No better proof is required that it is possible to render the waters of our surface water supplies the ideal water of the future than can be furnished from a careful study of the results obtained at their experiment station in Lawrence through the most thorough and exhaustive treatment of the subject of sand filtration of surface waters. Also from the object lesson presented in the practical working of a system of sand filtration in the city of Lawrence, designed by Hiram E. Mills, a member of the State Board of Health, which has been the principal factor instrumental in reducing the death rate from typhoid fever in that city from an average per year of 11.26 per 10,000 living for a period of five years (1886 to 1890, inclusive) to one of 1.86 per 10,000 living for the year of 1896. Had the death rate for 1896 continued as large as in the former average, the deaths from typhoid fever from this cause in Lawrence would have been sixty-three instead of the ten deaths that did actually occur. The pages of the reports of the State Board of Health are replete with examples that might be presented to you, all tending in the same direction. The dangers are fully set forth; additional methods for protection are fully explained, an abundance of material is present that might be used to more fully show the character of the water and the best methods to be used for its purification. Sufficient, however, has been said to draw your attention to a subject, the importance of which is such that its discussion will never cease until it is fully recognized that a proper system of filtration is as necessary an adjunct to a surface water supply as is the storage reservoir constructed to impound the storm waters in our streams and retard their flow to their natural home in the ocean until they can be used to supply our needs during the annually recurring periods of a minimum rainfall.

In conclusion, I wish to express as my opinion, that the surface water supplies of Massachusetts are not inferior in quality to those

of the other States of our Union; and also that a surface water supply if properly purified by filtration will furnish water of better character for domestic use than can be secured from an underground system of supply.

DISCUSSION.

MR. CLARK. I think we have all enjoyed this paper of Mr. Haskell's very much; I know I have, and I think it is a good sensible paper. There is much to be said in favor of a surface supply in comparison with a well supply. It is generally a softer water, and one which causes less trouble in many domestic and manufacturing uses. I think the Imperial Board of Health of Germany has probably set us a good example in not allowing the use of any surface water supply until it has been filtered, although we have of course many practically unpolluted surface supplies. Certainly by filtration we can get rid of most of the objectionable features which many of our supplies have. We can remove the organisms, those which we know to be harmful as well as those about which we are doubtful. We can also remove a large proportion of the color, and although we may not have a water even then, in a great many cases, as colorless as that from driven wells, still we will have a good water and a soft water.

MR. RICHARDS. It seems to me that with the outside public, at least, there is a misunderstanding of what we mean when we characterize a water supply, as we sometimes do, as "disagreeable," or as "dangerous," or as "not good water." There ought to be some term employed which would define more closely just what we do mean. Most surface waters that have odors and tastes are not dangerous, though they may be called disagreeable. If a water is polluted with sewage, then it might be called dangerous. Now it does not seem to me it is fair to say that a surface water supply taken from a sparsely settled district, where the watershed is sparsely settled, and where there is reasonable care taken in policing the watershed, should be filtered. I think, taking the cost into consideration, as you always have to, that that water might be said to be a reasonably safe water, and I believe that the assertion that all natural waters whether polluted or not should be filtered, is unwarranted.

DESCRIPTION OF THE SEPARATE HIGH PRESSURE FIRE SERVICE SYSTEM OF PROVIDENCE, R. I.

BY EDMUND B. WESTON, C. E., CONSULTING ENGINEER.

[*Read Sept. 16, 1898.*]

The water supply of the city of Providence is taken from the Pawtuxet River, in the town of Cranston, and pumped into a reservoir located upon a hill about one mile distant. From this reservoir, the elevation of the water line of which is 180.5 feet, the water flows into the city by gravitation, directly supplying a second reservoir within the city limits, the elevation of the water line of which is 162.5 feet, and also that portion of the city which is below an average elevation of 90 feet. To supply that part of the city above an average elevation of 90 feet, a high service reservoir, the elevation of the water line of which is 274.75 feet, is located in the town of North Providence. The water is pumped by supplementary pumping machinery from the second reservoir above mentioned, or from the low service mains, into the high service reservoir. This supplementary pumping machinery can also supply the high service district if the high service reservoir should be out of service, by pumping directly into the pipes. In addition to the regular pipe and hydrants of the low service in the centre of the business section of the city which is below an elevation of 90 feet, there is a separate high pressure fire service system for protecting an area of about one-half of one square mile, which derives its supply and pressure from the high service reservoir and pumps.

Before the high pressure fire service was installed, the district in which it is located already possessed what would be considered in the majority of cities an ample protection against fire, namely: an abundant water supply, large supply mains and distribution pipes, and 153 hydrants averaging from 200 to 400 feet apart in the streets

where they are located. The static pressure at these low service hydrants averaging from 75 to 40 pounds per square inch, according to the elevation.

The high pressure fire service system which was completed last October, was built by the direction of the City Council in accordance with the recommendations of the Board of Fire Commissioners. The plans of the work were prepared to conform to the general ideas of the Fire Commissioners in regard to the streets in which the pipe was laid, the location of the hydrants and the quantity of water to be delivered at different points under a specified pressure. The plans also took into consideration a possible addition to the system in the future if it should be deemed necessary, of an auxiliary stationary pumping plant to be located within or immediately adjacent to the district, which would be used solely for fire purposes, and with which the pressure could be increased 50 pounds more than could be obtained from the high service reservoir and pumps.

The high pressure fire service is not to be used for any purpose but fire protection, and its only connections are those leading to the street hydrants of the system. The average static pressure in the pipes is about 44 pounds more than it is in the pipes of the low service at the same elevation. The area of the district which should be able to derive a benefit from the high pressure fire service is about $\frac{56}{100}$ of one square mile. The elevation of about three-fourths of the area of the district, which includes the most compactly built up business portion of the city, ranges trom 10 to 20 feet. The elevation of the remainder ranges from 20 to 70 feet.

The supply of water is taken from the 24-inch high service main leading from the high service supplementary pumping machinery, previously mentioned, to the high service reservoir. This main acts both as a supply and delivery main to and from the high service reservoir, and the high pressure fire service pipe is connected to it at a point a little more than three miles from the reservoir. If the high service reservoir should be out of service, the high service supplementary pumping machinery will supply the high pressure fire service in addition to the regular high service distribution, by pumping directly into the pipes. A check valve is set upon the high pressure fire service pipe near its junction with the high service reservoir main in order to shut it off from the regular high service

Providence R.I.

Plan showing the Pipe and Hydrants of the New High Pressure Fire Service.

The Irregular lines show, in pounds per square inch (at the surface of the ground along which they run), the Approximate Static Pressure of Fruit Hill Reservoir.

if the fire pressure should be increased 50 pounds by the aid of the auxiliary pumping plant which has been referred to as a possible addition to the high pressure fire service system in the future.

The total length of the pipe of the high pressure fire service is 29,409 feet; namely: 4,189 feet of 24-inch pipe, 23,004 feet of 16-inch pipe, and 2,216 feet of 12-inch pipe. There are 89 hydrants connected to this pipe.

The average depth of the centre line of the pipe is about 6.25 feet from the surface of the ground, which is about 1.6 feet deeper than that of the ordinary water pipe. The pipe was laid at this depth in order to pass under the ordinary water pipe and other obstructions that were already in the ground, as well as a precaution against the freezing of the water in the pipe of the fire service, which would be more likely to occur on account of its comparative stagnation. As an additional safeguard against freezing, and more especially as about 300 feet of the 24-inch pipe is exposed to the weather on account of passing under two bridges, and owing to the raising of the grade of a few feet of pipe in two or three instances in order to pass over large sewers, a by-pass has been located between the high pressure fire service system and the low service for producing a circulation in severe cold weather, and three blow-offs are attached to the system at convenient points for the same purpose.

For more than four months during the winter of 1897 and 1898 the gate of the by-pass connecting with the low service has been open about two turns, allowing a discharge of about 40,000 gallons per 24 hours into the low service, and every morning during the same period, two of the blow-offs have been opened for about fifteen minutes, allowing a discharge of about 1,100 gallons in addition to that passing through the by-pass. The circulation in the fire service produced by these discharges has prevented the minimum temperature of the water from falling below 37°.

The static pressure at the hydrants of the high pressure fire service ranges from 116 to 85 pounds per square inch, according to the location of the hydrants. At 71 of the 89 hydrants it is more than 100 pounds. The pipe is of such a large size that under ordinary conditions the pressure will not fall below 100 pounds in the centre of the fire service district when an average rate of 5,000,000 gallons per 24 hours, or 3,472 gallons per minute is being drawn from the pipe.

At a test soon after the system was completed, at a hydrant having an elevation of about 10 feet, a good bodied stream of water, flowing at the rate of about 950 gallons per minute, was discharged from a $2\frac{1}{2}$-inch "ring nozzle" to a vertical height of about 137 feet above the ground. The nozzle was supplied through a 12-foot length of $3\frac{1}{2}$-inch hose leading from a jumbo connection, which was fed from the hydrant by two lines of $3\frac{1}{2}$-inch and one line of $2\frac{1}{2}$-inch hose, each 50 feet long.

The plan (Plate No. I), shows the high pressure fire service pipe as it is laid in the district which it is intended to protect, and the hydrants connected to the same. The contour lines show in pounds per square inch (at the surface of the ground along which they run), the approximate static pressure due to the high service reservoir. The pipe and hydrants of the low service, which are laid in all of the streets, are not shown upon the plan.

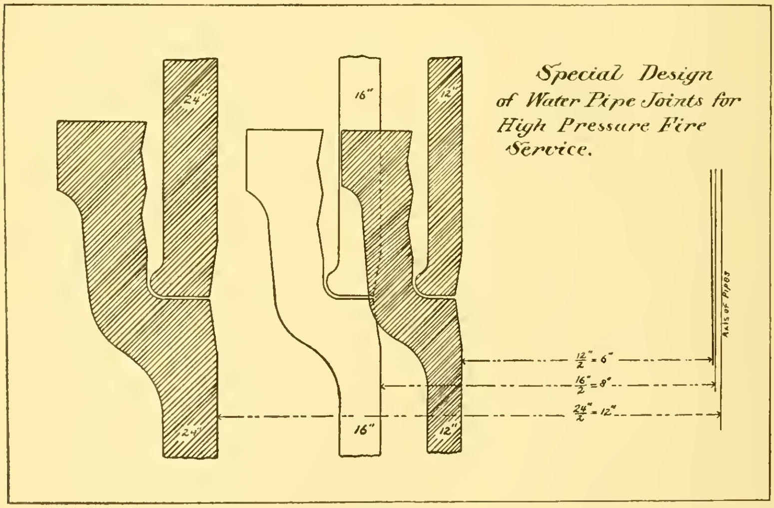


Plate No. II.

Plate No. II shows a section of the pipe joints, which have a double groove for increasing the resistance of the three inches in depth of lead, which was used for making the joints. These joints were especially designed for the high pressure fire service pipe.

Plate No. III shows the method followed in securing the curved pipe of the system. As will be seen by the plate; collars, lugs and screw bolts were used. This method of securing the curved pipe, which was also especially designed for the high pressure fire ser-

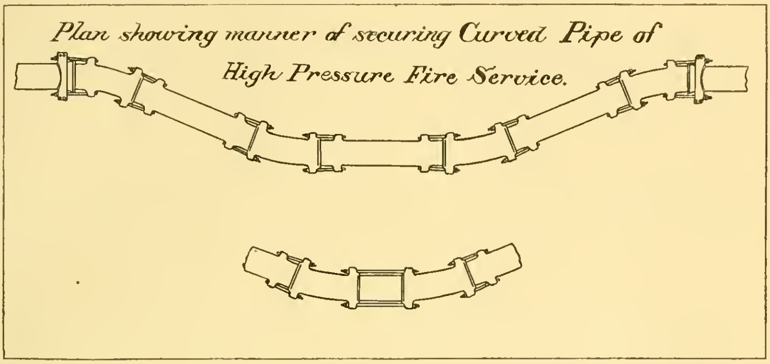


Plate No. III.

vice, has given great satisfaction, both on account of the quickness with which the work could be done and the security of the same after it was completed.

The high pressure fire service seems to give general satisfaction to all concerned. The insurance rates have been reduced five per cent within the district which it is intended to protect, and an authority in regard to insurance has estimated that the holders of policies within the district will save in ten years, owing to smaller premiums being paid, an amount which will exceed the total cost of the entire system. During a large fire last December, in the opinion of the fire commissioners and others, the system practically "paid for itself," as the fire was kept within the walls of the building in which it originated, by the aid of the high pressure fire service, otherwise it might have spread over a large area and caused a great additional loss of property.

The amount appropriated for building the high pressure fire service was $150,000. The expenditure was $143,175. The estimated value of the pipe and fixtures on hand, to be used for further extension is $3,425, and the cost of the system as completed is $139,750, or $4.75 per lineal foot of pipe laid.

The expense of laying the pipe was considerable; namely: on

account of its being laid in paved or macadamized streets; on account of its unusual depth, which necessitated generally the sheeting of the trench in which the pipe was laid; on account of bad quicksand, which was sometimes encountered, that required the dumping of coarse gravel into the bottom of the trench in order to secure a satisfactory foundation for the pipe, and on account of about 4,300 feet of 16-inch pipe being laid in winter, which necessitated the thawing by artificial means a depth of from 12 to 24 inches of frost at the top of the pipe trench. (See appendix).

It should be remembered, as has already been mentioned, that in designing and doing the work a much larger increase of pressure was anticipated in the future. An increase of pressure, however, is not probable, for at least sometime to come, as the pressure at the present time is eminently satisfactory to the fire department.

The plans and special designs mentioned above were made under the personal direction of the author. The author also directed the construction work. The loss of head due to the friction of the water flowing in the pipe, which was based upon what it may be after the pipe has been ten years in service, was computed by a new formula (dependent upon the age of the pipe), which was constructed by the author.

APPENDIX.

A DESCRIPTION OF THE METHOD THAT WAS FOLLOWED IN THAWING THE MACADAM SURFACING, STONE BLOCK PAVEMENT AND EARTH, WHICH COMPOSED THE UPPER PORTION OF THE TRENCHES OF THE HIGH PRESSURE FIRE SERVICE PIPE THAT WAS LAID IN WINTER.

The thawing was done by steam, with the aid of two bottomless boxes without ends, placed side by side. Each box was 72 feet long, built in six sections of 12 feet, having a top width of 20 inches, a bottom width of 24 inches, and a height of 12 inches. The sections were constructed by nailing spruce boards to skeleton frames, one of which was located at each end of a section. The capacity of the combined boxes was 518 cubic feet. The ends of the boxes were closed by being covered with bagging and earth,

and the joints between the sections were covered in a similar manner. Earth was shoveled around the lower sides of the open bottoms of the boxes where they came in contact with the ground, to prevent the escape of steam. A small portable boiler in which the steam was kept at about 50 pounds, was used for generating the steam. One line of ¾-inch steam hose was run from the boiler through the bagging, into one end of each box for a distance of about 2 feet. A small open space was left in the bagging at the other end of each box, to produce a circulation of steam. At the close of a day's work the boiler fire was banked, the hose removed from the boxes and their ends entirely closed, in order to retain the steam and heat which they contained, as long as possible, and thereby derive all of the benefit that could be obtained from the same during the night.

The total expense of constructing both of the boxes did not exceed $20. The frost averaged from 12 to 24 inches in depth. The top length of trench, 4 feet wide, that was thawed, was 4,300 lineal feet, or an average of about 71 lineal feet per day. The average cost of thawing was 6.7 cents per lineal foot, or 1.7 cents per square foot of ground surface area.

DISCUSSION.

Mr. French. The system described in Mr. Weston's paper is certainly of value to all interested in preventing fire waste. There is nothing so good as a gravity system. It is working nights and Sundays and holidays, and there is no delay in starting pumps. In large cities the steamers are gotten into operation very quickly, to be sure, but in smaller towns it takes some little time to get everything going. The department is not called out very often, and consequently there is apt to be a delay, so that the advantage of a high pressure system supplied by gravity is obvious. Apparently somewhere about 100 pounds pressure is enough for ordinary fire service, and perhaps is as much as the firemen can conveniently handle. The higher pressure makes the streams, when short lines of hose are used, rather unmanageable. With 100 pounds as the limit, hydrants must however be placed at such frequent intervals that lines of hose longer than 300 feet will not be necessary, otherwise the hose friction becomes a serious loss.

There is one point which it is to be regretted we cannot ask Mr.

Weston about, and that is just how he figured the pipes for friction loss. Some experiments made last summer in Lowell by the proprietors of the locks and canals furnished some interesting data as to their old pipes. There was a 12-inch pipe coming from their reservoir to the mill system, nearly a mile in length, which was laid in 1849, and was not tar coated or otherwise protected from corrosion. Some tests were made of that pipe in connection with the general testing of the fire system. The water was discharged through some large nozzles, the pressures at the nozzles being measured by a piezometer with an ordinary Bourdon gauge, and the quantity flowing thus determined. The pressures were then taken at a hydrant some distance up stream from the point where the nozzle was connected, using again an ordinary gauge. The loss of pressure was shown by the difference between the ordinary static head and the pressures recorded with different quantities of water flowing. It was found that this 12-inch pipe, fifty years old, had become so corroded that it had no greater capacity than a new, clean 8-inch pipe, which means that the friction loss was roughly about five times what Mr. Weston gives in his published tables for new, clean 12-inch pipe. Some years ago, I am told, when that pipe was being repaired, a short section was taken out and it was so covered with tubercles that a 10-inch plug was the largest which could be drawn through, and that probably knocked off the tops of some of the largest bunches, showing how very serious the incrustation had become. There was another 12-inch pipe nearly parallel to this one, laid about thirty years ago, and that showed a loss, tested in the same way, of about twice what Mr. Weston gives, speaking roughly. That was a tar coated pipe. These pipes were not straight, there were many bends in them. Similar tests at the same time, of 8-inch uncoated pipes laid about fifty years ago, showed a carrying capacity less than a new, clean 6-inch pipe. Such data shows the effect of time in reducing the carrying capacity of a pipe, and indicates that a fire system which is designed to be thoroughly efficient, after twenty-five or thirty years of use must be laid out on a liberal enough scale to allow for this unavoidable corrosion.

CORRESPONDENCE.

Mr. Weston. Mr. French has referred to the author's tables published in 1896, which show the loss of head due to friction in

pipes, and compares experimental data relating to an originally tar coated 12-inch pipe about 29 years old with losses of head given in the author's tables for new pipes. A comparison of the results obtained during the experiments made with this pipe, as contained in the "Test of the Fire System Belonging to the Proprietors of Locks and Canals made in 1897," with losses of head that have been worked out from an originally tar coated 12-inch pipe 29 years old, by the aid of the tables in the author's book, which are arranged to apply to old pipes that were originally coated with tar as well as for new pipes, show that the losses of head thus deduced do not differ very materially from average experimental results derived from the 12-inch pipe above mentioned :

Gallons of water flowing in the pipe per minute.	Loss of head in pounds per 1,000 feet in an originally tar coated pipe 12 inches in diameter and 29 years old.	
	From diagram showing results of experiments above referred to.	Computed by Weston's tables.
500	0.76	0.55
1000	2.30	2.22
1500	4.70	4.99
2000	8.00	8.87

METHODS FOR THE DETERMINATION OF COLOR AND THE RELATION OF THE COLOR TO THE CHARACTER OF THE WATER.

BY FREDERICK S. HOLLIS, BIOLOGIST, METROPOLITAN WATER WORKS, BOSTON, MASS.

[*Read Sept. 14, 1898.*]

THE COLOR OF SURFACE WATER.

In 1880, Tidy[1] stated that "The color of a surface water is caused by the peaty or vegetable impurities, and the color varies with the condition of the vegetable matter present." He stated further that the color imparted by a recently formed peaty material is yellowish green, that by a recent peat a brownish olive green, while that obtained from old peat is a true brown or coffee color entirely free from the olive tint.

Dr. Drown[2] reached the same conclusion by preparing artificially colored water by extracting leaves in distilled water, and showed also that for the same color the amount of albuminoid ammonia was less in subsequent extractions.

	Color.	Albuminoid Ammonia.
First infusion of leaves	0.80	.0494
Subsequent infusion of same leaves.	0.80	.0174
Infusion of old leaves	0.90	.0072

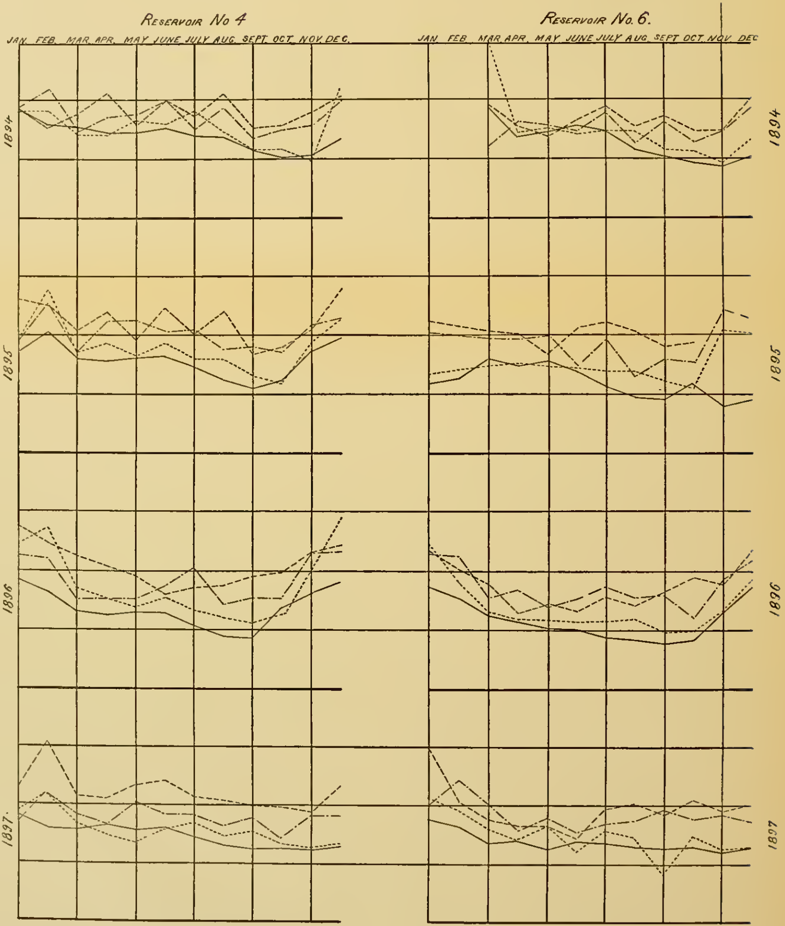
It was further shown that by decolorizing a surface water having a color of .80 or .90 by means of hydrate of alumina, about 85 per cent. of the albuminoid ammonia was removed. Infusions of animal matter, while they have very little color, are very rich in albuminoid ammonia, which, however, is not removed by treating with hydrate of alumina.

[1]Jour. Chem. Soc. 1880, p 293.
[2]Technology Quarterly, 1888, p. 256.

PLATE A.

BIOLOGICAL LABORATORY, BOSTON WATER WORKS

Color, 20 divisions = 1.00 ————
Oxygen Consumed, 20 divisions = 1.00 ············
Loss On Ignition, 20 divisions = 2.00 —·—·—
Albuminoid Ammonia In Soln., 20 divisions = .0200 — — — —



Analyses presented by Mrs. Richards[1] of the residue from Boston tap water[2] and the dark water from Cedar Swamp in Westborough, Mass., as well as that of humic acid[3] derived from brown vegetable mould show the following results:

	Color of water.	Carbon.	Hydrogen.	Nitrogen.
Residue, Boston tap water	0.57	30.71%	5.96%	7.68%
Residue, Cedar Swamp water....	4.00	43.72	3.92	4.82
Humic acid	——	50.40	4.80	3.60

Solutions which agree well in color with a peaty water can be prepared from caromel or charred sugar which contains no nitrogen.

The foregoing analyses, showing the closer relation between the color and the carbon contents of the residue obtained on evaporation, agree well with the fact that the color of a water follows most closely the determination of the amount of carbonaceous matter in solution, as shown by the test of the oxygen consumed or the power of the water to take oxygen from potassium permanganate.

In the case of a normal or unpolluted surface water which receives a constant supply from an uninhabited area there is generally a close agreement between the color, the oxygen consumed, the loss on ignition and the nitrogen as shown by the albuminoid ammonia in solution. This is due to the fact that it receives the different constituents in about the same relative proportions.

This is shown on Plate A for the Ashland and Hopkinton reservoirs of the Metropolitan Water Works (formerly reservoirs No. 4 and 6 of the Boston Water Works) in which the fluctuations of the various components are seen to follow the color in a general way. The greater regularity of the line representing the color is due to the fact that it is the average of weekly readings while the others are based on single monthly analyses.

In the case of such unpolluted dark waters the color is a ready means of forming a somewhat rough comparative estimate of the condition of the water with regard to the presence of those substances represented by the oxygen consumed, the loss on ignition and the albuminoid ammonia in solution. From this rather close agreement between the color and the other substances present in the case of a

[1]Jour. Am. Chem. Soc., Jan. 1896.
[2]H. T. Gallup. Thesis, Mass. Ins. Tech., 1894.
[3]Berthelot. Compt. Rend., 569, 1892.

water from an uninhabited area we pass by steps according to the extent of pollution to the other extreme in the case of a highly polluted colorless water, especially in the case of pollution by sewage, where there is no connection between the color and the chemical impurities.

Water in contact with soil takes up the extractive matter from the organic constituents of the soil, which appears as chemical impurities and also adds to its color. This is of special interest in connection with the determination of the depth to which a site for a reservoir needs to be stripped.

By a careful study of the soils from the site of the proposed Wachusett reservoir made by the Massachusetts State Board of Health,[1] it was found that 50 grams of surface soil in contact with one liter of water for eighteen hours imparted a color of from .20 to .60 according to the nature of the soil, while in the case of land recently cleared of good sized timber, even a greater amount of color was imparted, and that this soil continued for a long time to impart color to the water.

The amount of color imparted, as well as the material dissolved, as revealed by chemical analysis, decreased rapidly in soils from below a depth of 9 to 11 inches, and it was decided that an amount of organic matter represented by a loss on ignition of from 1.5 to 2 per cent. of the weight of the sample dried at 100° C. was a safe amount to leave in the bed of a reservoir.

The apparent color of a surface water is often influenced by an increase in the turbidity of the water. Such an increase in color caused by turbidity was noted in Framingham reservoir No. 3, and its influent stream during the construction of the Sudbury reservoir on the influent stream above it. Most of the work causing the turbidity was done during the years 1894 and 1895.

	Color. Reservoir No. 3. Influent	Color. Reservoir No. 3 at dam.
1893	.71	.71
1894	1.00	.77
1895	1.05	.82
1896	.75	.62
1897	—	.58

It is our custom to report the color of the unfiltered water, as an

[1]Rept. Mass. State Bd. Health, XXV.

increase of color due to turbidity is apparent, generally persists, causing an increase of color in the reservoirs lower in the series, and any increase of color of the lower layers due to stagnation is only safely estimated after transportation to the laboratory by the color of the unfiltered water.

INCREASE OF THE COLOR OF WATER DUE TO STAGNATION.

Twice a year, generally during April and November, the surface layer of a body of water acquires the temperature of greatest density, 39.2° F., and in consequence sinks to the bottom, thus causing a circulation of the water of all depths. At other times there is no cause for the water of different depths to mix except the action of the wind, which only rarely extends to a depth of thirty feet.

Thus the water at the bottom of a deep pond or reservoir is stagnant during the greater part of the year and, unless the water is of exceptional purity, marked changes take place in the character of the water, one of the most noticeable of which is a material increase of color. The chemical analysis of such a dark water from the bottom of a stagnant pond or reservoir shows an accumulation of organic matter which is undergoing a putrefactive change.

Water if exposed freely to the air absorbs oxygen in amounts varying with the temperature from about 1.00 per cent. of its volume, just above the freezing-point to 0.54 per cent. at 88° F. In the case of water of the surface of a pond, which is at all times exposed to the air, this supply of oxygen which is held dissolved in the water is sufficient to oxidize the products of decomposition as they are formed and when used up it is immediately replaced. In the lower stagnant layers this supply of oxygen is soon exhausted and, as no more can be taken up, the products of decomposition cannot be carried to their final or harmless form until the spring or autumn overturn of the water. Indeed the avidity of the decomposing organic matter for oxygen is such that, when the water is once deoxidized, the nitrates contained in the water are reduced and the oxygen contained in them appropriated. Such a water is characterized by low nitrates and high free ammonia as well as by high albuminoid ammonia and oxygen consumed.

Under these conditions iron is reduced and taken into solution

in considerable quantity, amounting in some cases at the bottom of Lake Cochituate to nearly 2.00 parts per 100,000.

This iron in solution adds materially to the increase of the color of a stagnant water and, upon bringing a sample to the surface, increases the color and unpleasant appearance still further by its oxidation and separation.

A supply in which any considerable proportion of its water at the bottom has undergone these changes due to stagnation during the summer always shows an appreciable increase in color at all depths at the time of the autumn overturn of the water.

An idea of the increase of color due to stagnation is obtained by comparing the color readings of the water at the surface of Lake Cochituate with those from the bottom (60 feet) at the time of maximum stagnation.

	Color.
Lake Cochituate, surface	.22
" " bottom (60 feet) on collection	1.20
" " " " after exposure to the air	3.70

The temperatures and colors for the surface, mid-depth and bottom of Lake Cochituate during the period of one year showing the effect of stagnation are given on Fig. 1 and Fig. 2. Lake Cochituate was selected for the study of the effects of stagnation on account of its great depth at a single point where no mixing of the water occurs except during the spring and autumn overturn, but it is not to be understood that Lake Cochituate is for that reason an objectionable source. The slight increase in color of the water of the upper layers after the autumn overturn shows clearly that the amount of water affected by the stagnation is very small compared with the total volume of the water of the lake.

It is interesting to note in this connection that of the reservoirs of the Metropolitan system, the one which has shown least tendency to these unpleasant results receives a very dark colored water from an uninhabited area. Temperature readings show that it is, like the other reservoirs, stagnant during the greater part of the year.

The study of many of the dark surface waters of the State has shown that dark water of such character is remarkably stable and unobjectionable from a sanitary standpoint.

COLOR IN GROUND WATER.

Ground water when derived from a source having a covering of peat, which is not infrequently the case when the site has been selected in a valley so as to realize the greatest yield from the watershed, is often colored through the influence of the peaty layer. This peat may be of comparatively recent origin forming the surface or, if the wells are of great depth, the peaty layer may represent an accumulation of some former period, in which case its influence is generally even more marked. Oxygen is taken from

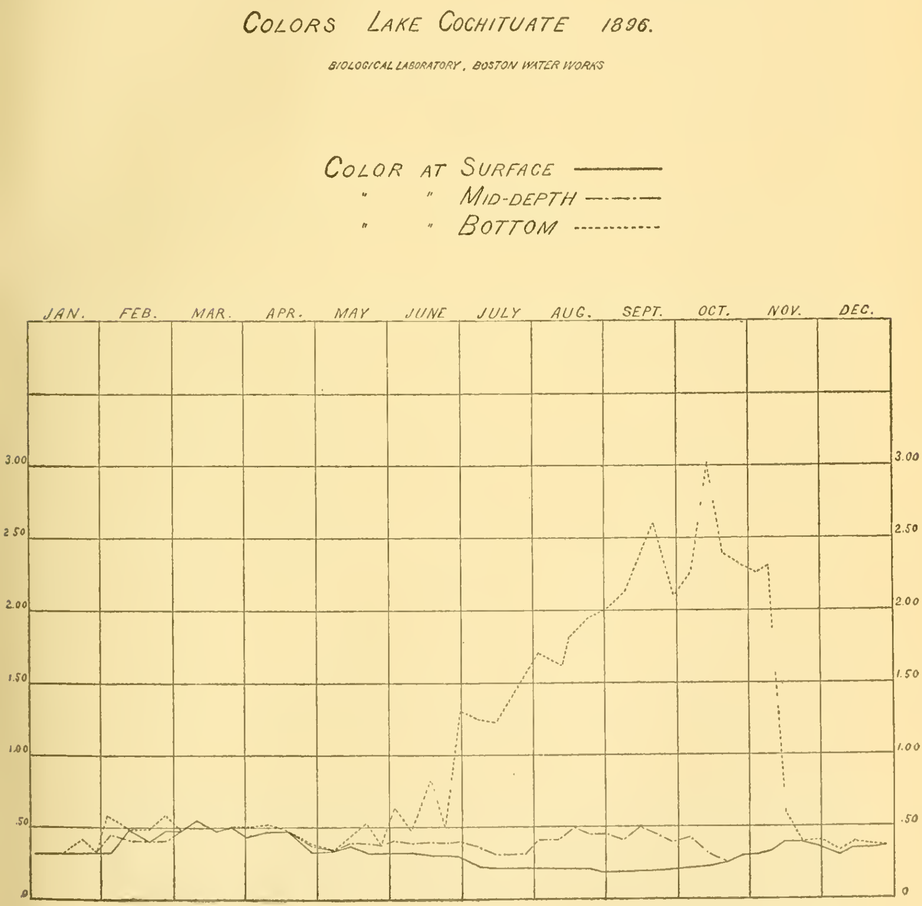


Fig. 1.

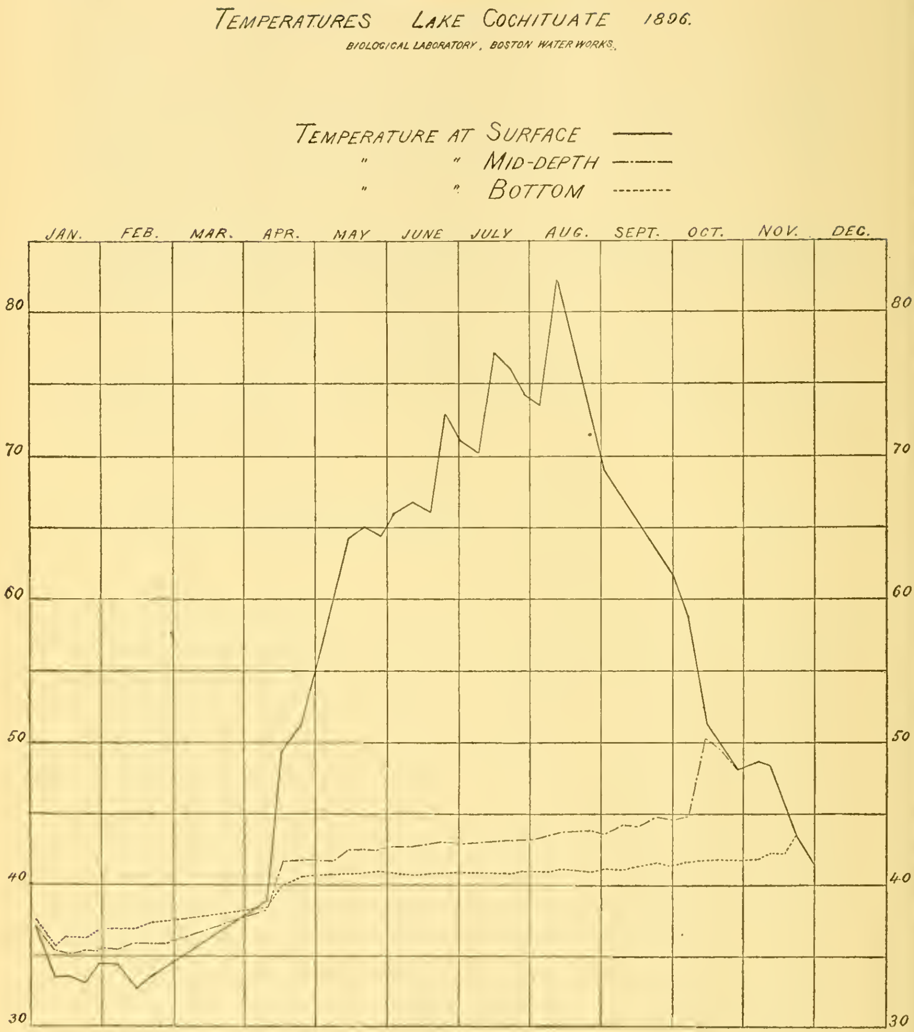


Fig. 2.

the ground water by the decomposing organic matter held in solution and, as there is little opportunity for replacing this supply of oxygen when once exhausted, a condition similiar to that in the stagnant layers of ponds often ensues and iron is frequently dissolved in the water.

On bringing such a water to the surface, the iron which it contains is slowly oxidized but, on account of the power of some organic substances to prevent the complete precipitation of iron, it is removed too slowly by natural means to admit of its use as a source of supply.

Peifke and Fränkel devised a means of removing the iron from certain Germany city supplies derived from ground water, depending upon the rapid oxidation of the iron, by passing it in the form of spray through a column of coke and the subsequent removal of the precipitated iron by means of rapid filtration through sand. In some cases in this country the iron has been sucessfully removed by aeration obtained by spraying and subsequent rapid filtration, while in others the iron is apparently more firmly held and mechanical filtration involving the use of a coagulant has been considered necessary.

That many excellent supplies are drawn from ground water is evidence that the oxygen held dissolved in the water is not in all cases entirely used up during the passage of the water through the ground and in such cases no appreciable amount of iron is dissolved. Analyses made on December 1st, 1892, of water flowing from two tubular test-wells at Medford, Mass., showed that the water contained oxygen in solution amounting in one to 23.7 and in the other to 24.1 per cent. of saturation.

Water flowing from four of the many tubular wells of the Newton, Mass., water-supply on November 19, 1892, was found to contain oxygen dissolved which amounted to 12.92, 3.48, 0.89 and 3.28 per cent. of saturation.

Water from this source has at no time since shown the presence of any considerable amount of iron in solution.

METHODS FOR THE DETERMINATION OF THE COLOR OF WATER.

From the foregoing it will be seen that in the case of a normal surface water there is a certain general agreement between the color and some of the chemical substances generally determined by analysis. This chance for comparison is lost in the case of a polluted water that receives material which appears in the chemical analysis as impurities but bears no connection to the color-producing material. In the case of a water colored by iron there is no opportunity for comparison between the color and the organic impurities.

If, therefore, a method for the determination of the color is desired it is necessary to resort to some other means.

The most ready means is a direct comparison of the color with some standard of color produced in a definite way, and this has been done by a variety of methods. Most of the methods have some special advantage or are particularly well adapted for the determination of the color of the class of water for which they were used.

The method of varying the depth of the column of water to match a definite and fixed color standard, and that of comparing a definite depth of water with varying depths of standard, or a set of standards of the same depth but different intensities, or with a set of colored glass plates have been used.

The medical commission appointed to investigate the sanitary qualities of certain sources with reference to the increase of the Boston water-supply* made their observations on the color of the water by means of an instrument in which the depth of the column of water was varied so as to match the intensity of color of a plate of brownish-yellow glass. While this method served to make a comparison of the color of the water from these different sources, most of which are similar dark colored waters, it is not a method to be recommended for general use as the selection of the glass of particular hue is an arbitrary one which would not be well suited for the comparison of water from souces of a different character. It would also be difficult or impossible to describe such a color standard in a way that it could be duplicated for use in different laboratories. The method did not survive the purpose for which it was proposed.

A method has been recommended consisting of filling half full a two-foot tube of considerable diameter provided with plate glass caps. When this is held horizontally the water occupies the lower half and the lower half of the circular field is illuminated by light which has passed through the water. The comparison is made by placing colored plates or small bottles containing colored liquids in front of the upper half. This is a cumbersome method, the accuracy of which depends upon the selection of suitable color standards and, moreover, few of our waters can be read in tubes of such length.

It may be interesting to note that four-foot glass capped brass

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*City Document, Boston. No. 102, p. 104.

tubes, having a diameter of four inches, were found very useful at the Experimental Filter Station of the Boston Water Works for comparing roughly the color and also the turbidity of the light colored effluents from the filter-tanks.

The instrument commonly used for the estimation of the color of water in England is the *Tidy Colorimeter which consists of two two-foot tubes with glass ends, the ends opposite the observer being closed by ground glass. The tubes are mounted one above the other on a stand, the water to be examined placed in one and a corresponding amount of distilled water in the other to compensate for loss of light due to the depth of water. The comparison is made by placing glass wedges filled with different colored liquids in front of the tube containing distilled water, and the position of these wedges is changed, thus interposing more of one color or the other, until the resultant agrees with the color of the sample. The solutions used are bichromate of potash for the yellow and sulphate of copper for the blue, and the color is reported in terms of so much yellow and so much blue as read off on a scale marked on the wedges.

While this method may serve for the estimation of the color of water of English supplies, most of which are light colored, and of effluents from filter-beds it became necessary to make the solutions at least ten times as strong as recommended in order to secure sufficient of the yellow hue to match our surface waters when viewed in tubes of such length and, moreover, the red which is so prominent in most of our surface waters is entirely ignored. On account of the use of wedges, the color varies somewhat on different sides of the circular field and it is also necessary, on account of the use of two tubes, to compare the color of the water as seen with one eye with the color of the standard as seen with the other.

The recommendation of Prof. A. R. Leeds,† that the Nesslerized ammonia standards used in estimating the amount of ammonia be used as standards for the comparison of the color of water is of special importance to us as it was very generally adopted in this country, and all results are reported in terms of this standard or of some scale based directly or indirectly upon it.

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*Crookes, Odling and Tidy. Chem. News 43, 174. Am. Chem Jour. 14, 300.

†Proc. Am. Chem. Soc., 2, 8.

The Nessler scale consists of a set of seventeen standards of a volume of fifty cubic centimeters containing from 0.1 to 5.0 c. c. of dilute ammonia solution, each cubic centimeter of which contain .01 mgr. of NH_3. When treated with the Nessler reagent they have a brown color not unlike that of our surface waters, the intensity of which varies with the amount of ammonia solution added to each standard. The standards, as well as the water to be examined, are placed in glass tubes, closed at one end, of a diameter of 15 to 20 milimeters and 300 milimeters in length.

The turbidity of the standard increases with the amount of ammonia solution present, which makes it difficult to match the water against the higher standards, and moreover, the material causing the color of the standards is not permanent and is liable to precipitate by handling the standard tubes on account of its unstable nature. Recent work has also shown that the intervals of the scale are not regular.

NATURAL WATER STANDARDS.

Standards made by diluting a dark surface water with distilled water to match the different standards of the Nessler scale have been used successfully. Standards made in this way have the same hue as the waters to be matched, as well as a turbidity which corresponds well with that of surface waters, but the irregularities of the scale are the same as the Nessler standards, which they are made to match.

Natural water standards are fairly permanent if protected from the light, but gradually grow lighter and must be compared frequently with a fresh set of Nessler standards.

By means of the Lovibard tintometer[1], a satisfactory set of natural water standards can be standardized in terms of definite plates of colored glass. By comparing a new set of standards with these plates they can be made at any time comparable with the previous set.

The tintometer consists of two tubes, arranged not unlike those of the Tidy colorimeter, in one of which the standard under examination is placed and in the other the graded colored glasses. The color is represented by the aggregate of the tint numbers of the glasses required to match the standard. No attempt is made to

[1]Ellen H. Richards and J. W. Eellens. Jour. Am. Chem. Soc., XVII, 1896.

correct the irregularities of the scale of the natural water standards, which we have already seen are the same as those of the Nessler standards.

PLATINUM STANDARD.

According to the platinum standard, introduced by Mr. Allen Hazen,* "the color of a water is the amount of platinum, in parts per ten thousand, which in acid solution, with so much cobalt as will match the hue, produces an equal color in distilled water." In practice, a standard having a color of 5.00 is prepared by dissolving 1.246 grms. of potassium platinic chloride, (=.5 grm. platinum) 1.000 grm. of cobalt chloride (=.25 grm. cobalt), and 100 c. c. of concentrated hydrochloric acid in distilled water and making up to one liter.

Dilute standards for matching the color of the water are prepared by diluting quantities of this stock solution to 50 c. c. with distilled water. By diluting 1 c. c., 2 c. c., and 3 c. c. to 50 c. c., colors of 0.1, 0.2 and 0.3 are obtained.

The intervals on the platinum standard are similar to those of the Nessler scale. The two standards are practically the same at 0.40, below which the platinum standards are lighter colored, and above which they increase regularly, so that a color of 1.50 on the platinum scale is equal to 2.00 on the Nessler scale.

The platinum standard is permanent if protected from dust, and as it is prepared by weighing accurately quantities of a definite crystalline chemical compound, it can be prepared in any laboratory. The intervals of the scale are regular, the color is directly proportional to the depth, and it is free from the objectionable turbidity noticed in the case of the higher Nessler standards. The color is not influenced by the temperature or method of preparation as is that of the Nessler standard.

In 1892, a form of colorimeter was devised by Mr. W. E. Foss under the direction of Mr. Desmond FitzGerald[1] for use at the Experimental Filter Station of the Boston Water Works, which embodied much that was new in its application to the estimation of the color of water. The following description and plates are reproduced from the description of the colorimeter published in the Report of the Boston Water Supply Department.

*Am. Chem. Jour., XIV., No. 4.

[1]Ann. Rept. of the Water Supply Dept., City of Boston, 1893.

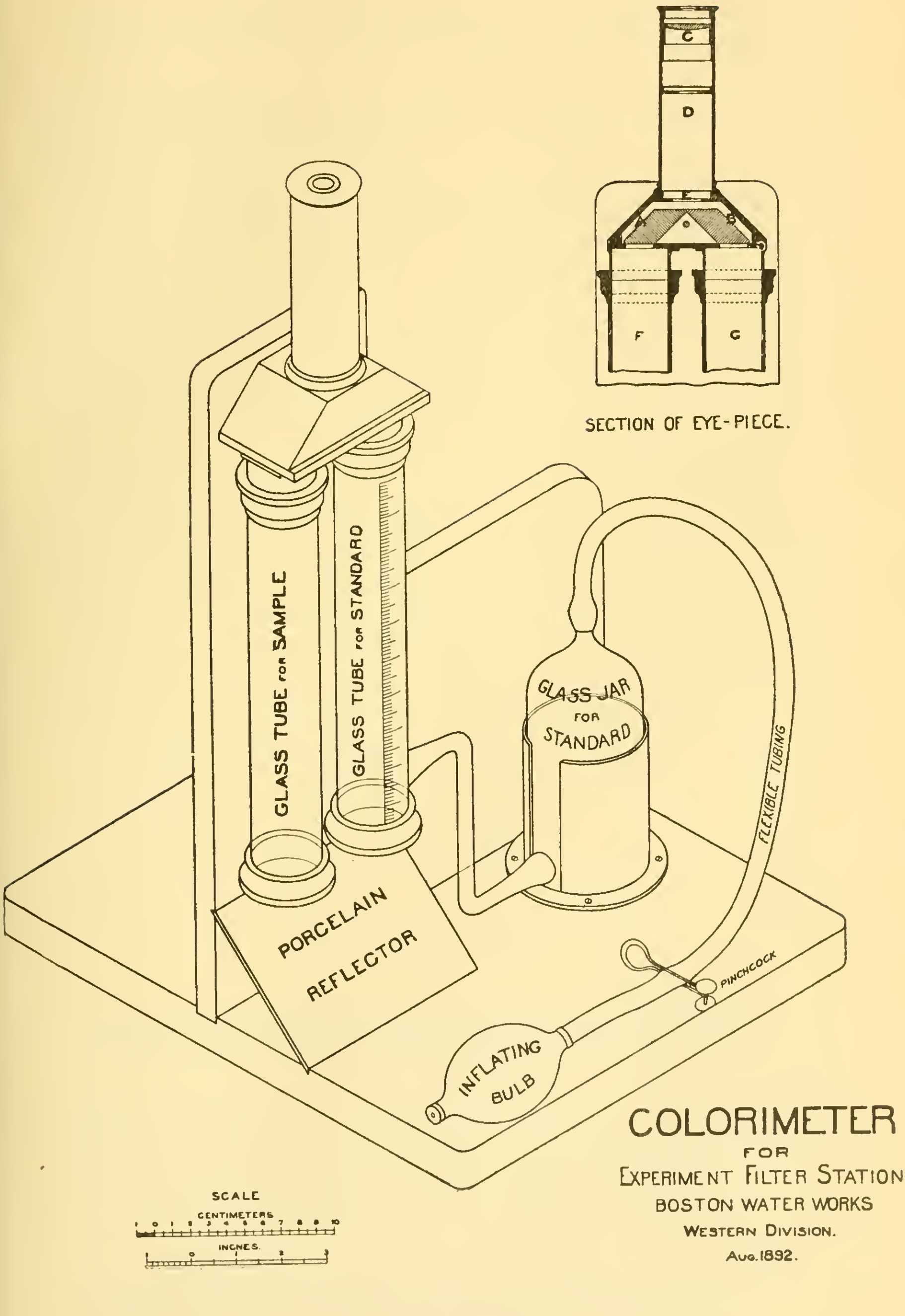
An isometric projection of the complete instrument and a section of the eye-piece are shown on the following plate. "The latter consists of two totally reflecting prisms A and B and a magnifying lens C. The lens is free to slide in the brass tube D, so that it can be focused on the upper faces of the prism. The field of view is cut down to a circle by a diaphragm E, at the lower end of the tube D.

"Rays of solar light from some uniform source, after passing through the column of water of a depth of 200 mm. placed in tube F, which has a plate glass end, enter the prism A, and emerging, illuminate one-half of the circular field of view. Rays of light from the same source, after passing through the standard solution in tube G, enter prism B, and are totally reflected at its surfaces, and emerging, illuminate the other half of the field of view."

"The colors produced by the absorption of the two liquids can then be readily compared and brought to the same value as follows: The standard solution is held in a glass jar and is connected by means of a glass tube with the standard tube. The top of the jar is furnished with a piece of flexible rubber tubing terminating in an inflating bulb. By means of the latter the observer increases the depth of the standard in the standard tube, which has a total length of 200 milimeters, until the color produced on the field of view matches that of the water in the other tube; he then closes the pinch-cock on the tubing and reads the color of the water from the scale on the standard tube."

With such a colorimeter both the method of varying the depth of the column of water to match the color of a definite depth of standard solution and that of varying the depth of the standard to match the color of a definite depth of water can be used.

Before adopting the method of varying the depth of the standard to match the color of a definite depth of water, already described, a series of careful experiments were made in order to determine the relative accuracy of the two methods. It was found that if the first of the two possible methods is used, in which the depth of the standard remains constant, the depth of water can be varied safely only between certain limits. As the bottom of the tube is approached the change in color, corresponding to any given decrease in depth of water, increases rapidly. With waters varying in color from 0 to 1.00 it was found that at least three standards are necessary in



COLORIMETER
FOR
EXPERIMENT FILTER STATION
BOSTON WATER WORKS
WESTERN DIVISION.
AUG. 1892.

order to have a difference in reading of one division (=2 mm.) on a total scale of 200 mm. amount to an error of not more than four per cent.

This is shown graphically in the upper diagram on Plate 2, where the colors obtained by calculation are plotted for several different standards. The depth of water in the tube is represented by the abscissas, and the calculated color when using the standard marked on each curve by the ordinates. The point at which the error in a color reading, resulting from an error of one scale division in reading equals four per cent. is shown by a cross on each of the curves. For all waters having colors darker than this, a new standard must be employed. The necessity of employing different standards for waters having a range of color between 0 and 1.00 makes this method impracticable.

The method of varying the depth of the standard solution to match the color of a definite depth of water was found to give readings of equal value in all parts of the tube, and correct readings of water having color of from 0 to 1.00 were obtained with a single standard, as shown by the following table:

Color of Standard.	Depth of Sample under Examination.	Depth of Standard in m. m.	Calculated Color of Water.	Color in m. m. for 10 Scale Divisions.
1.00	200 milimeters.	200	1.00	.10
1.00		180	.90	.10
1.00		160	.80	.10
1.00		140	.70	.10
1.00		120	.60	.10
1.00		100	.50	.10
1.00		80	.40	.10
1.00		60	.30	.10
1.00		40	.20	.10
1.00		20	.10	.10
		0	0	.10

The average of two sets of readings by independent observers of a set of platinum standards in the colorimeter, having the 1.00 platinum standard in the jar, show that the maximum error does not exceed .02. In case greater accuracy is desired for a water having a low color, a 0.50 standard can be substituted for the 1.00 standard in the jar.

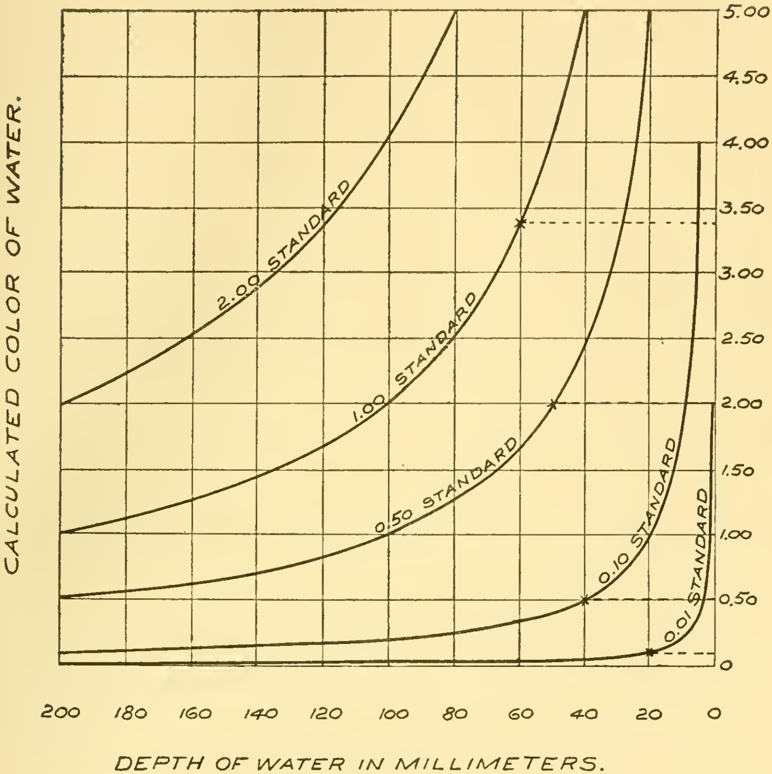
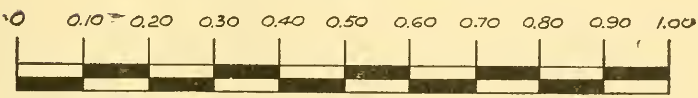
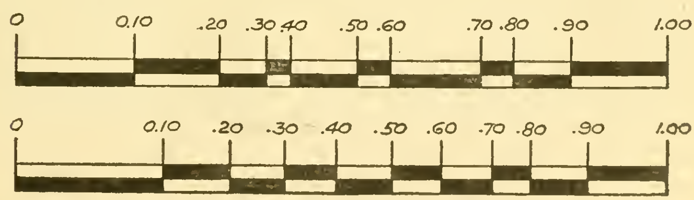


PLATE 2.

UNIFORM SCALE.



NATURAL WATER OR NESSLERIZED-AMMONIA SCALES.



Platinum Standard.	Colorimeter Reading.
0.10	0.115
0.20	0.22
0.30	0.32
0.40	0.40
0.50	0.50
0 60	0.595
0 70	0.70
0 80	0 80
0.90	0.895
1.00	1.00

By thus reading the color of the different members of the scale of the nesslerized ammonia and natural water standards, the irregularities of the scales was determined, which are shown on Plate 2. The upper scale represents one of uniform graduation, such as the platinum scale has been shown to be. The middle scale represents the graduation corresponding to the nesslerized ammonia and natural water scales, as determined by two independent observers, using the 1.00 natural water standard in the jar. The lower scale represents the graduation of the nesslerized ammonia or natural water scale which is the average, as determined by three independent observers, of fifteen sets of natural water standards, read both in the Nessler tubes and in the colorimeter.

The following uniform scale was obtained by diluting some of the 1.00 natural water standard to form the lower members of the scale and reading them in the colorimeter against some of the original 1.00 standard in the jar, which shows clearly that the irregularities are due to the method of preparation of the standards and not to any cause arising from varying the depth of the standard during the reading.

Dilution of 1.00 Standard.	Reading on Colorimeter.
.10	.095
.20	.21
.30	.295
.40	.405
.50	.52
.60	.60
.80	.80
1.00	1.00

For reading the color of waters darker than 1.00 it is necessary to use a shorter depth of water for comparison, or perhaps better to dilute with distilled water so as to bring the color within the range of comparison with the 1.00 standard.

I also think from my experience that it is advisable to do so in the case of exceptionally turbid waters, even though the apparent color when read in the depth of 200 mm. may not be more than 0.70.

Such a colorimeter with the platinum standard has been in use in the laboratory of the Boston Water Works from 1892 until 1898 and in the laboratory of the Metropolitan Water Works from January 1, 1898 until the present time, and has been found to give a ready means of reading colors accurately and quickly. The only difficulty experienced is one which is experienced alike by all methods, namely, the variations in hue of surface waters with the season, as such waters are redder in the spring and summer and yellower or even greenish in the autumn and early winter. This we have already seen is due to the nature of the coloring matter present in fresh or old leaves and in vegetable coloring matter.

Opportunity for changing the color of the platinum standards to match such variations of hue of the water is afforded by the fact that the amount of cobalt which imparts the red component of the color, is not a fixed quantity and is to be added in such quantity as will produce the desired hue.

Appended is a table for use in converting color readings on the Nessler or natural water scale to those of the platinum scale.

Table for Transforming Color Readings from the Nessler and Natural Water to the Platinum Standard.

Nessler or Natural Water Standard.	0	1	2	3	4	5	6	7	8	9
0	0	.02	.04	.06	.08	.09	.11	.13	.15	.17
.1	.18	.19	.20	.20	.21	.22	.23	.24	.24	.26
.2	.26	.27	.27	.28	.29	.29	.30	.31	.32	.32
.3	.33	.34	.34	.35	.35	.36	.37	.37	.38	.38
.4	.39	.40	.40	.41	.42	.42	.43	.44	.45	.45
.5	.46	.47	.47	.48	.48	.49	.50	.50	.51	.51
.6	.52	.53	.53	.54	.54	.55	.56	.56	.57	.57
.7	.58	.58	.59	.59	.60	.60	.61	.61	.62	.62
.8	.63	.64	.64	.65	.66	.66	.67	.68	.69	.69
.9	.70	.71	.72	.73	.74	.75	.77	.78	.79	.80
1.0	.81	.82	.82	.83	.84	.84	.85	.86	.87	.87
1.1	.88	.89	.89	.90	.91	.91	.92	.93	.94	.94
1.2	.95	.96	.96	.97	.98	.98	.99	1.00	1.01	1.01
1.3	1.02	1.03	1.03	1.04	1.05	1.05	1.06	1.07	1.08	1.08
1.4	1.09	1.10	1.10	1.11	1.12	1.12	1.13	1.14	1.15	1.15
1.5	1.16	1.17	1.17	1.18	1.18	1.19	1.20	1.20	1.21	1.21
1.6	1.22	1.23	1.23	1.24	1.25	1.25	1.26	1.27	1.28	1.28
1.7	1.29	1.30	1.30	1.31	1.32	1.32	1.33	1.34	1.35	1.36
1.8	1.36	1.37	1.37	1.38	1.39	1.39	1.40	1.41	1.42	1.42
1.9	1.43	1.44	1.44	1.45	1.46	1.46	1.47	1.48	1.49	1.49
2.0	1.50									

DISCUSSION.

In answer to the question as to the cost of the apparatus constructed under the direction of Mr. FitzGerald, Mr. Hollis could give no definite information, but he thought that one could probably be made for about $100. It was specially constructed and to his knowledge it is the only one in existence.

Mr. Whitney. I should like to ask Mr. Hollis how much skill is necessary in getting a satisfactory or accurate reading of the scale from the instrument?

Mr. Hollis. Very little indeed. I often have a young man in the laboratory, who does not ordinarily read the colors, check my readings, and he will read to within one division, that is a hundredth of the scale. There is a point, however, in connection with that which should perhaps be mentioned, namely, that two people may not obtain the same color reading of a sample of water owing to the fact that the eyes of one observer are more sensitive than those of the other to some component color of the sample. I have repeatedly found that my eyes are more sensitive to red than those of some people, which occasionally causes the color of a sample of water to appear very slightly darker to me than to another observer.

Mr. Haskell. I would like to ask Mr. Hollis if it is not possible to read as accurately through the small tube filled with the platinum cobalt standard as with this instrument?

Mr. Hollis. The readings obtained with a set of platinum standards in Nessler tubes are not as accurate as those obtained with the colorimeter as, when standards are used in Nessler tubes, the intervals between members of the set are never less than one-tenth. Between zero and one there are ten tubes representing one-tenth, two-tenths and so on, and any closer reading has to be done by interpolation, while on the colorimeter there are one hundred divisions between zero and one. The colorimeter was devised mainly to eliminate this uncertainty arising from the interpolation between tenths. Each division on the colorimeter is one-tenth of that between consecutive standards as prepared in tubes.

Mr. Haskell. Wouldn't it be possible, Mr. Hollis, for two experts reading samples of the same water by the tubes not to vary over three points? For instance, the standards varying ten points, say from .40 to .50, if you read .43 the other expert would not be very liable to read over .46 or under .40, would he?

Mr. Hollis. He would not.

Mr. Haskell. That is, the personal error in using the tubes would certainly be within three points.

Mr. Hollis. We have fixed it at two points as the result of our readings; but of course it is much more difficult to read in that way and it requires a longer time. By the use of this instrument the comparison is made very quickly.

Mr. Haskell. Of course I recognize the beauty of that instrument in doing accurate work, but we cannot all secure one of those as readily as we can the tubes.

Mr. Hollis. I think three-hundredths would be the maximum variation in reading by the tube method, and it is possible to reduce it to two, as we have found in reading the effluents from the filter tanks.

Mr. Haskell. I would like to ask Mr. Hollis if he knows the depth in Lake Cochituate at which this point of stagnation he mentioned takes place?

Mr. Hollis. That is a subject I studied very carefully, more particularly in the summers of 1890, 1891 and 1892. The maximum stagnation is quite close to the bottom (60 feet,) but the amount of oxygen begins to decrease, I should say, not very far below the mid-depth, (30 feet.) It seems, however, to depend a great deal on the character of the water and the character of the bottom of the reservoir. I remember examining a reservoir 23 or 24 feet deep for dissolved oxygen and finding at the depth of, I think, 12 feet that the water contained no oxygen whatever. That shows a very rapid disappearance of the oxygen held in the water, because there is but a short interval even during the summer, when there is not sufficient wind to stir the water to that depth.

Mr. Haskell. I didn't fully understand what you said about the color of the water in those two bottles (referring to samples exhibited by Mr. Hollis) and the depth below the surface at which the water was taken. I understood you to say that the color at the surface of the water was .22, and of the water taken at a lower depth, 1.20; am I correct?

Mr. Hollis. Yes, that is so. It was .22 at the surface and 1.20 at the bottom, but on exposure that which was 1.20 increased to 3.70 on account of the oxidation and final separation of the iron.

Mr. Haskell. Are we to infer from that that the water at

that depth is six times as poor in character as that at the surface?

Mr. Hollis. I think it would not be exaggerating it at all to say it was six times as poor, because it would be absolutely unfit for use. The water at the bottom during the period of stagnation has a marked unpleasant odor, frequently characterized by hydrogen-sulphite, and we have this large amount of iron in solution which would prevent the use of the water, and in every way it is objectionable. On the other hand, don't let me give you the impression, please, that there is any large amount of stagnant water in Lake Cochituate, for that is not so. There is simply a deep hole in the lake where this stagnation takes place at a great depth; there is no possibility of stirring it up, and that is the reason we selected it for study. The water of the lake as a whole is good, and after the over-turn, when all this bad material is brought to all depths, the character of the water of the whole lake is affected but very little, so the stagnation is comparatively unimportant with reference to the water of the entire lake. It simply affords a good opportunity to study what we are liable to meet with in other cases.

Mr. Haskell. I have known a small pond in which the point of stagnation was not over 6 feet below the surface. That is, if a sample of water which showed no oxygen, showed that the oxygen was entirely consumed, I suppose that would be evidence that the water had arrived at a stage of stagnation; and I found that condition in one instance existing not over 6 feet below the surface under the ice. Now, in view of that fact, isn't it probably that in small ponds, where the wind does not have an opportunity to stir the water as it does in blowing across a long pond, there is often a state of stagnation very near the surface, or much nearer, at any rate, than you would find in Lake Cochituate.

Mr. Hollis. Yes, sir, it is so, and especially in a small swampy pond with a muddy bottom. I have in mind such a small pond which was stocked with carp, and during one winter every fish in the pond died, which I think was undoubtedly because of the lack of a supply of oxygen.

The President. Are there any more questions to be asked? This is a subject in which I think we are all interested, certainly I am particularly so.

Mr. Whitney. I have seen a statement somewhere as to the depth of soil which the Metropolitan Water Board decided should

be taken off from the site of the Wauchusett Reservoir, but I have forgotten now what it is, and I would like to ask Mr. Hollis to tell me, if he remembers.

Mr. Hollis. I haven't seen the figures, in fact I didn't know that they had been definitely determined. But as appears from this article published by Dr. Drown, it is his opinion that an amount of organic matter represented by loss on ignition of one and a half to two per cent. is a safe amount to leave in, because those soils taken from a depth which showed that amount were on the dividing line between those which imparted a great deal of chemical impurity and color to the water and those that did not. He further said that below a depth of 9 to 11 inches, the soil in most localities showed a rapid falling off in the organic compounds. In connection with that I will say that with Dr. Drown I made a very thorough study of the site of the Hopkinton reservoir, and we were not satisfied at that time that the loss on ignition would give satisfactory data, because if there is any clay present all of the water is not driven off at 100, the temperature at which it is dried. We made organic combustions to determine the amount of carbon absolutely present in a weighed quantity of the soil after careful mixing, and from this percentage of carbon computed the corresponding percentage of the organic matter, knowing as we did from microscopical examination the character of the organic matter present. It was largely the portion of the root-stocks represented by the bark, those being higher in carbon than the woody portion, which had almost always decayed away. These experiments were repeated by Dr. Drown, and he found that the measure, as I have given it, of from one and a half to two per cent loss on ignition agreed with what was found to be a safe amount of organic matter arrived at in this way.

Mr. Haskell. Mr. Hollis stated that they gathered a sample of earth and put it to soak. and in a certain length of time it added a certain amount of coloring matter to the water, and that that process was continued for a certain period. I would like to ask him if there was a diminution in the amount of color from time to time, and if it seemed probable that in the not distant future the color-giving material in the sample might have been entirely eliminated, so it would not color the water at all?

Mr. Hollis. That would certainly be a most interesting thing to find out, but the report, as I think, was given in such a way that

we cannot determine from what was stated whether that would be the case or not. The experiments reported were made in this way. Most, I think all of the samples from open lands and swamps were treated as follows: Fifty grams, or at least a definite amount of soil, was treated with a definite volume of distilled water, with which it was allowed to stay in contact for eighteen hours, a definite period. Then the color was taken and the analysis made. In the case, however, of two, at least, of the samples from land from which a heavy growth of timber had recently been removed, they were treated, not successively, but for a longer time, and the color was read after standing eighteen hours, after standing three days, and after standing a week. Up to the end of the week the color of the sample increased regularly; but they did not try it in the way in which Mr. Haskell suggests, which would be a good way, that is make successive extractions. Dr. Drown's experiments seem to show in the case of leaves that you can go on extracting for quite a long while, and I know my own work showed that that was the case. In the case of logwood, the first extracts are yellow, after which it imparts for a long time a deep purple color to fresh portions of water. I suppose it is only fair to assume that the same is true of most woody matter that holds coloring matter. Of course there is a limit, but it is not easily reached, at least, not in the laboratory. I suppose it might be different in the large volume of water in a reservoir which is constantly at work.

Mr. Fuller. I would like to ask Mr. Hollis in regard to filtered water, as to the different depths through which water is filtered, whether the result would depend upon the depth of the filtering material; that is whether the color would decrease in proportion to the depth of the filtering material?

Mr. Hollis. I think it undoubtedly would, if filters were constructed so shallow that they did not remove the desired quantity. All of those I have in mind, or at least the great majority of them, were built of the depth of about 5 feet, the depth which would be used in practice, and it was a comparison of a large number of different materials rather than different depths, and a study of the rates of flow of each.

Mr. Fuller. Five or six feet of filtering material would remove the larger proportion of the color, I suppose?

Mr. Hollis. A very large proportion; practically all from a colored surface water.

Mr. Haskell. I would like to ask Mr. Hollis if he knows definitely, so he can tell us on the standard of colors, from some of his experiments how thoroughly the color was removed in a proper filter?

Mr. Hollis. Almost entirely, unless the rate of filtration is very high. For instance, the average color of the water which was taken from the Chestnut Hill reservoir was about .50, and after filtration, it would read perhaps only a few hundredths. The same result has been obtained at Lawrence in the State Board's work.

Mr. Fuller. I would like to ask Mr. Hollis if there is a great difference in the tenacity with which the coloring matter is held in different waters, or is it all practically alike? That is, if you had water from different sources of the same degree of color, would it be equally easily removed from all of them?

Mr. Hollis. I don't know, Mr. Fuller, that I can answer your question definitely. That could only be told from experience with a large number of sources, and my experience has been limited almost entirely to surface waters from the watersheds used by the Boston Water Works. The only other cases that I can call to mind are cases where filters were used for other purposes than for the removal of color, that is the removal of bacteria from a polluted source. I think all of our waters from similar watersheds showed the same result.

Mr. Codd. I would like to ask at what time of day the temperatures were taken?

Mr. Hollis. The temperatures are taken in connection with the collection of samples from our different reservoirs, which I should say was between seven and nine o'clock in the morning. The samples are collected for us once a week at all the reservoirs, at an hour sufficiently early so that they can be taken to a forenoon train and sent to our laboratory. That is particularly interesting just at present when we have cool nights and mornings. If they are taken at the usual time they will very soon begin to fall off in the case of the influent, which becomes cooled down through the night, whereas, if they are taken later during the day they will show higher temperatures.

Mr. Chace. In answer to Mr. Fuller's question with regard to the difficulty of removing the color in different waters, I suppose he is familiar with the reports of the State Board of Health a few

years ago, when the Hyatt Filter Company was flourishing and was deluging up with statements that they could remove the color from any water with one grain of alum precipitate, that, according to the experience of the chemists of the State Board, there were waters in Massachusetts which required 17 grains of alum to remove the color.

Mr. Bancroft. Perhaps I can throw a little light on Mr. Fuller's question. We are running a mechanical filter, and at certain times, when there is apparently no higher color than at other times, although I have made no color tests, it is very much harder to remove the color than at other times. Sometimes, indeed, it would require more alum to remove the color than we care to put in.

Mr. Whitney. I would like to ask Mr. Bancroft if this persistency of color is particularly noticeable in any month in a series of years, and if so, to what he attributes it?

Mr. Bancroft. It has usually been in the month of June, but this year it was later. I have attributed it to the surface water working down through the peat. We get more iron at that particular time, it is a time when the water is low in the ground, the ground water is low, and we get more iron than we do at high water: and when there is a large amount of iron there is more color as the iron begins to precipitate, although when the water comes out of the ground as it is first pumped there is apparently no more color in it than at other times.

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THE DESIRABILITY OF MAKING WATERSHED AREAS AND SANITARY DISTRICTS COTERMINOUS.

BY R. E. MIDDLETON, M. INST, C. E., M. INST. M. E.

(FELLOW.)

(*Read at a Sessional Meeting held on April 6th, 1898.*)

As was remarked by Major Flower in his address to the Leeds Congress 1897, the division of the country into watershed areas, for purposes of water supply and drainage, which areas shall be made coterminous with sanitary districts, appears to be very desirable.

The writer pointed out in his paper on the "Pollution of Rivers from an Engineer's point of view," read at the same congress, that rivers and streams have, from the earliest times, been put to two different and antagonistic uses, they have been considered to form the natural source of supply for water to be used for drinking, culinary and ablutionary purposes and at the same time to be receptacles for all animal, vegetable and mineral refuse. It has even been maintained in quite recent years that the latter is the natural and primary duty of every river and stream.

It is scarcely necessary to point out to a Society of Sanitarians that the first use of a river is to provide water for animal life. Secondly it may provide power for grinding corn, for the weaving of fabrics, and for such other purposes as may be beneficial to the riparian inhabitants. Thirdly it may be used for carrying the persons and property of those who live near it, and the necessaries of life from point to point. Lastly and not until the other requirements have been satisfied, it may be used, in a manner which shall not defeat its primary obligations, for the removal of refuse matter.

Needless to say the requirements of a crowded population and of an advancing civilization have materially altered the second and third items of legitimate use, mills are in many cases built and

worked, not for the supply of the necessaries of life to the inhabitants in its immediate neighborhood, but for the production of goods to be supplied, perhaps to distant countries, the only benefit accruing to the people of the district being found in an increased demand for labor and consequent circulation of money, the riches produced being diffused over a large area.

It frequently happens that manufacturies which originally depended on water for their motive power, have found the supply inadequate and unreliable on account of its intermittent character and resort has been had to steam, whereby a portion of the water has been taken from the river and has been diffused into the atmosphere as vapor, also the use of the water has not been limited to power, but large quantities have been employed for the cleansing of foul rags or other articles for mixing with materials used in the processes of manufacture and for the removal of chemicals from partially manufactured goods.

Advancing civilization, especially in respect of rapidity and facility of transport, has both enabled and obliged the manufacturer to locate his business in a position where the supply of raw material with which he deals can be obtained most easily and therefore most cheaply, where wages are low and where motive power is cheap.

As the land of the country will no longer supply sufficient corn for the consumption of the population, and as each year brings a larger and larger supply of cereals to our shores from foreign countries, flour milling is no longer so profitable a business, when conducted under the old conditions on small rivers, as it was in former times ; larger mills and more elaborate machinery are now required for the production of the fine and white flour which is now used almost universally, the old fashioned flour or wind-mill is becoming obsolete, and is being replaced by modern mills driven by steam power and situated near a sea-port.

On the other hand processes of manufacture, which require large quantities of water for cleansing purposes, are increasing, and the mill which, in the old days, provided food for its district, has become a source of pollution in itself, and a centre of pollution on account of the population which has grown up around it and which is dependent on it.

In every direction we find the tendency to pollute is on the increase, at the same time that the demand for a supply of pure water is likewise increasing, while the area from which a supply can safely be drawn is diminishing and many rivers have become impossible as sources of water supply, in all cases on account of the amount of trade refuse which has been passed into them.

In the mining districts the banks of the rivers and streams become tip heaps for ashes and scoria, often containing poisonous ingredients, all sorts of refuse are thrown into them, they stink and are corrupt, but filthy as they are they are not so offensive as are the waters which are used for washing rags, or woollen goods, for cleansing skins, or the waters that are near large breweries.

Undoubtedly the pollution which is most dangerous to man is that produced by man himself. The untreated excreta of the human being are at all times a source of danger, but when they proceed from a diseased human being they may carry with them the germs of death to many fellow creatures, and with the increase of population comes increasing difficulty and increasing costliness in dealing with the refuse, animal, vegetable and mineral, which results from human aggregation.

It seems to be doubtful if any danger is to be feared as resulting from the droppings of cattle when living in the open, and even if they are to some extent dangerous they are necessarily limited in quantity, for cattle cannot live in an area which will not easily disinfect all the manure which they produce.

Probably the artificial manures, if one may thus designate guano and fish in a putric condition, are much more to be feared than any natural manures; the fish are, however, in themselves, so offensive to the sense of smell that they are seldom used except for very high cultivation, such as hop gardens.

An endeavor has been made to point out in a brief but effective manner the causes which are producing an increased use of water for the supply of steam to engines, for cooling and other purposes in iron and steel works, for the cleansing and manufacture of the materials used in paper-making, fell-mongering, woollen and linen manufacture, brewing, in chemical works, and in a thousand other ways, much of such water being diffused into the atmosphere as vapor, while still more is so befouled as to be unfit for drinking, culinary or even for washing purposes.

In another direction the available water supply is also becoming more limited on account of the amount of land which is occupied by towns, villages and manufacturing centres, while both the increase in population, the demands of a higher civilization and the greater requirements for steam and similar uses, all call for a greater supply and a more liberal use of water.

Consequent on the increase in the size of our large towns the demand for water has led to an upsetting of all preconceived ideas as to the sources from which supplies should be obtained. Manchester obtains a supply, not from its own district but from Cumberland, Liverpool from Vyrnwy, Birmingham from the Elan Valley, and the London County Council would have us look to the Valleys of the Usk and Wye for our supply of water, and there does not at the present time seem to be any efficient conservation of the sources of supply for the use of those who are the natural heirs to it, namely those who are the first to receive it from the atmosphere and at whose feet it is running, either above ground in the form of streams, rivers and lakes, or below ground in tiny rills. Every town or village situated on the banks of the river or one of its tributaries has a vested interest in the maintenance of the purity of the water which flows towards it. Even if it does not obtain its water supply from the river or stream, still the fouling of the stream or river is an injury to the place, as causing a nuisance palpable to the sight or smell. At the same time, the same population desires to discharge its refuse into the same stream and to become a nuisance to its neighbor lower down on the course of the river.

It would appear on the face of it that the village situated nearest to the source of the river would have the best of it, for its inhabitants would be able to drink pure water while they would befoul what passed them by, and the population of places lower down on the course of the stream would each get a worse sample than the last and would pass it on in a still worse condition than that in which it came to them. Natural causes, the principal of which are, dilution by increase in the volume of the river, oxidation by air and light, the action of vegetation and sedimentation, tend to counteract the influences referred to, and unless the pollution is excessive in quantity the water becomes purer in the lower reaches of the river, rather than the reverse; and many streams which are de-

cidedly impure near their sources are purified before the water arrives at the lower reaches of the river.

The protection afforded to the consumer by the natural processes indicated above are not sufficient, unless they are supplemented by the power of an authority strong enough to curb the tendency of the human animal to get rid of the refuse which he creates, either as manufacturer or as an individual, with the smallest amount of trouble and at the minimum of cost. The disposal of sewage matter was, until quite recently, a subject not to be mentioned to ears polite, the matter was to be hidden away anyhow, so long as it was out of sight; so it was turned into cesspits, the positions of which were often forgotten, or into rivers, to be a nuisance to somebody else. Suddenly, sanitary science became rather the fashion than otherwise, and everybody talked of drains, with the usual result that much was done in a hurry which would have been better done if it had been longer thought over. Most large towns which can afford to spend money pretty freely have made efforts, at any rate, but with moderate success, to get rid of their sewage decently, and not to be greater nuisances to their neighbors than they could reasonably help, but the sewage disposal works of many small towns and villages are practically useless, because the inhabitants have not the money to keep the works for which they have paid, in order. In still other cases, sewage disposal works are conspicuous by their absence.

The selfish policy of turning all refuse into the nearest stream led to greater and still greater pollution of the water supply as time went on, and population and manufactures increased; the natural course of procedure which puts the provision of a pure and sufficient supply of water first and the disposal of sewage second was reversed, and the position became intolerable; moreover, the earlier efforts of legislation were directed to the provision of sewage disposal, while omitting to require that this necessary stipulation should be preceded by an ample supply of water.

Subsequent legislation has inclined to leave the cart before the horse and to subordinate any question of water supply to that of sewage disposal, making the latter compulsory, while the former is to a large extent permissive.

Consequent on this inversion of obligations the Rivers Pollution Act of 1876 is exceedingly tender in dealing with vested interests

in sewers and in the pollution of streams, and experience has shown that it is entirely insufficient to curtail the increasing tendency to pollute, notwithstanding the precautions which have undoubtedly been taken in many cases to prevent it. Later Acts have not, except as regards special localities, provided any adequate cure for the evil and then only within the last few years and in the face of the most convincing evidence and in cases of absolute necessity.

Considering the constitution of the authorities which have to administer the Acts dealing with the provision of water supplies, with the disposal of refuse and the pollution of rivers, it is scarcely to be expected that the result should be otherwise than it is. It has been easier for the authority to get water from some other source, however limited its area, however doubtful its ultimate purity, than to face the difficulties of dealing efficiently with the sewage which the same authority must get rid of. All authorities have had conflicting interests to consider when dealing with river pollution, and in all cases the preservation of the river in its pristine purity has been subordinated to the requirements of mill owners, for power purposes, of canals, for purposes of navigation, and of towns and villages desirous of getting rid of their refuse in the most summary manner and at the least possible cost, without consideration of any habitations placed below them on the course of the stream.

In this manner enormous drainage areas are becoming useless for purposes of water supply, and large towns are compelled to tap distant and at present unused and uncontaminated sources of supply, though at great cost, and are rapidly taking from unoccupied districts the water which at some time may be wanted for the inhabitants themselves. The future centres of the industries of the country cannot be predicted with any certainty. Already within the memory of man great cities have sprung into existence where formerly were only villages or desolation.

It seems reasonable that each district should supply its own needs, both in respect of water supply and sewage disposal, but this cannot be done unless water supply, a pure water supply, be put first and sewage disposal be subordinated to it by rigorously enforcing the obligations consequent on the aggregation of large bodies of men in centres of industry.

It is scarcely to be expected that the authority which desires to discharge the refuse of its district into the stream, (and as it draws its water supply from a point higher up does not injure itself,) should be urgent in the prevention of the pollution of the river for the benefit of towns situated below it on its course and in which it has no interest.

It frequently happens that the difficulties in dealing with the sewage of a particular district are enormous, while the question of disposal would become quite simple if compulsory amalgamation were possible.

As has been very ably pointed out by Mr. Malcolm Paterson, M. Inst. C. E., in his pamphlet on "Compensation Discharge in the Rivers and Streams of the West Riding of Yorkshire," the system of compensation in water generally adopted is not by any means universally advantageous, even to those for whom it is provided, while it is destructive of the purity of the river. Mills which only work by day desire to have compensation water delivered to them during the day only, so that they may get the utmost advantages from it, but, as the water is delivered from the compensation reservoir which is situated near or at the head of the stream, the mill nearest the reservoir is the only one which gets the full benefit, while those which are situated further from the reservoir must either work abnormal hours, standing idle in the morning, or they must have sufficient reservoir capacity of their own to conserve the compensation water received during the night and use it in the morning, up to such time as the new supply from the compensation reservoir reaches them. Take the case of a mill situated twenty-four miles below the reservoir, the stream from which travels at three miles an hour and begins to flow at 6 a. m. The new supply does not reach the mill until 2 o'clock in the afternoon, and eight hours' supply must be stored at the mill if the miller is to get the full benefit of the supply.

During the night, at points near the reservoir, the stream is probably nearly dry, and any sewage passed into it must, when added to the decaying vegetation consequent on an intermittent flow, cause a nuisance. At points lower down the river this state of things exists during part of the day as well as during part of the night, and becomes even more objectionable.

Enough has, it is thought, been said to show that if areas of water

supply are to be efficiently safe-guarded, if rivers are to be preserved from pollution, if the mill-owners are to obtain the utmost benefit of the power at their disposal—but without injury to the general interests of the population,—and if the navigation, if there be any, is to be maintained, the present system of divided authority should be abandoned, and a combined and general policy should be substituted for it.

At present every authority is in conflict with its neighbor, conflict in interest if not in fact, and litigation and disagreement are too frequently the result.

There are, it is believed, cases where districts have benefitted greatly by the adoption of combined systems of drainage, as for instance in the case of the Rhondda Valley and the Pontypridd combined drainage. Here, instead of each district providing its own sewage farm, a difficult and somewhat dangerous proceeding in a valley of but limited area, the sewage of the towns in the Valley of the Rhondda, and in the Valley of the Taff from Aberdare to Cardiff, is carried in iron pipes down the valley of the river Taff, and is discharged into the Bristol Channel above the town of Cardiff. This work was, however, carried out entirely in one county, and it may not unreasonably be supposed that unless there had been a County Council having an equal interest in the whole drainage area of the Taff, the District Council of Ystrad-y-fodwyg, the Urban Sanitary Authority of Pontypridd, and the other parties interested in the disposal of the sewage might have been endeavoring to work each their own little sewage farm. to the discomfort of their neighbors, or might have been disputing between themselves without making any progress.

The three Ridings of Yorkshire, being of such large area, are intersected by considerable rivers which flow for the whole or nearly the whole of their courses through one county only, and here again, as might be expected, we find the County Councils taking considerable interest in the rivers which are their own undivided property, an interest which appears to have secured to the general public, to judge from the reports contained in Mr. Paterson's pamphlet, considerable advantages.

Most of our larger rivers, on the other hand, serve as boundaries or divisions between counties. For instance, the watershed of the Thames extends over 15 counties or parts of counties in which some

2,600 authorities, County, Borough, District and Parish Councils hold sway. The whole of these do not have jurisdiction within the watershed, but if the number given above be reduced by 20 per cent., or to 2,080, this figure will probably represent the number of authorities within the drainage area of the Thames.

The watershed of the Severn affects 12 counties and some 1,316 Councils.

The Cambridgeshire Ouse touches 8 counties and some 1,200 Councils.

There is no necessity for carrying the calculation further, but from the figures which have been given some idea may be formed of the conflicting interests existing in any watershed area.

A further consideration which appears to point in the same direction, namely, to the necessity for having some authority responsible for watershed areas, is that of floods. There are many districts in England which are periodically flooded with very disastrous results. While the floods last and immediately afterwards, there is great talk of what could, should and must be done, but it ends in talk, because the interests are so conflicting that before anything can be decided on, the matter has become ancient history, and the public mind has to be stirred up again by another flood, and still nothing results unless there is an authority with sufficient power and possessed of sufficient funds to enable it to deal with the question without directly touching the pockets of the ratepayers.

As has been pointed out, the Rivers Pollution Act (1876) does not provide powers of sufficient stringency to enable the pollution of rivers to be dealt with efficiently, and necessity has obliged certain existing authorities to apply for an extension of their powers, as in the case of the Mersey and Irwell Acts of 1892, and the Thames Conservancy Act of 1894, but these acts are purely local and it seems desirable that they should be made general and that an authority, in some respects similar to the Thames Conservancy Board, but with more expanded powers as regards the raising of funds, should have charge of each of the principal rivers in the country.

The Thames Conservancy Board before 1894 had only power over the tributaries of the Thames for ten miles from their junction with the main stream, and they could only deal with pollutions under the general acts, the operation of which was found to be tedious and ineffectual. They have, by the act of 1894, authority over the

whole of the watershed, and they can enforce their powers much more effectually than under the general law, by means of the following clauses:—

93. If any person does any of the following things, namely:

(1) Opens into the Thames or into any tributary any sewer drain pipe or channel whereby sewage or any other offensive or injurious matter whether solid or fluid shall or is likely to flow or pass into the Thames or into such tributary;

(2) Wilfully causes or without lawful excuse (the proof whereof shall lie upon him) suffers any sewage or matter aforesaid to flow or pass into the Thames or into any tributary down or through any sewer drain pipe or channel not at the passing of this Act lawfully used for that purpose;

he shall for every such offence be liable to a penalty not exceeding one hundred pounds, and to a daily penalty not exceeding fifty pounds.

94. (1) Whenever any sewage or matter aforesaid is caused or suffered to flow or pass into the Thames or into any tributary then, and in every such case, even though such sewage or matter aforesaid had been lawfully so caused or suffered to flow or pass before the passing of this Act, the Conservators shall give notice in writing to the person causing or suffering the same so to flow or pass requiring him within a time to be specified in such notice, but not being less than three months to discontinue such flow or passage.

(2) Provided that the Conservators may if they think fit at any time, and from time to time extend the time specified in such notice by another notice in writing.

(3) And provided that if any person to whom any such notice is given thinks himself aggrieved by reason of the time allowed either by the original or by any subsequent notice not being sufficient, he may not later than one month before the expiration of the time so allowed by writing delivered to the secretary demand an extension of such time, and in case the Conservators refuse to comply with such demand, the question of such extension shall be referred to an arbitrator appointed by agreement or failing agreement by the Board of Trade on the application of either party.

(4) Any person to whom any notice is under this section given by the Conservators shall notwithstanding anything in any other Act within the time allowed by such notice subject to any extension of

such time as in this section provided, discontinue the flow or passage of the sewage or matter to which the notice refers, and in default of so doing shall be guilty of a misdemeanor and be liable on summary conviction thereof or on conviction thereof on indictment to a penalty not exceeding one hundred pounds, and to a daily penalty not exceeding fifty pounds.

(5) Provided that notwithstanding anything in this Act or in any Act incorporated therewith any proceeding in respect of such a misdemeanor may be removed by certiorari into the High Court.

The same authority has also, quite recently, given considerable attention to the prevention of flooding.

In what manner the watersheds should be mapped out, whether the existing boundaries of Counties, Sanitary Unions, and Parishes should be adhered to, or there should be a general re-arrangement of these artificial divisions, is too large a subject to be dealt with in a paper of this character, time will not permit of the full consideration of so difficult a question.

The constitution of the proposed authority is also a matter of great complexity, especially as regards the method of raising the funds to be placed at their disposal, but it may be said that the body should represent every class and interest, and that its duties should consist in the conservation of the river, its banks, and navigation, if any, in the maintenance of its purity including that of its tributaries, in the encouragement of combination and efficiency in sewage disposal and in the prevention of floods.

The writer has endeavored to lay before his hearers a question which he considers to be of considerable importance but which contains the elements of much complexity, and he trusts that the members of the Institute will be able to throw more light on the subject.

Mr. Baldwin Latham (London) said he thoroughly agreed with all that Mr. Middleton had said in his most interesting and instructive paper. The question of controlling watershed areas, especially with regard to the purity of the water supplies of the people, was one of paramount importance. Every day one was brought into contact with the fearful consequences that arise from the pollution of drinking water, and indeed, he began to think there was no question from a sanitary point of view which is of

more importance than that of the water supplies of this country. When he said water supplies, he did not mean to confine himself simply to the surface streams, but to direct attention to a greater extent to those underground streams, which, being out of sight were often out of mind, the consequence being that they were polluted to a frightful extent in the immediate vicinity of the places from which the water supplies are drawn. In fact, it appeared that nearly all the epidemics of typhoid which have occurred in this country, with slight exceptions, have been traced to these underground sources of supply. These had been polluted and had never seen the light of day, which no doubt to a very considerable extent tends to destroy the germinal matter—so fruitful a source of disease. How this matter was to be dealt with was certainly a very large question. Sanitary authorities themselves and water authorities did not seem to appreciate the importance of securing a pure water supply. Only last year a bill was actually introduced into Parliament for making a reservoir in a small town in Sussex, where the overflow of the cesspools passed into the stream above the site of the proposed reservoir, and although that fact was pointed out to the committee, the bill passed. A fortnight previously a bill was brought before the committee of the House of Commons for the establishment of a gas works at Margate, and a most extraordinary position was selected for this gas works—in close contiguity with the aqueducts of the principal water supply of the town, which were only from 60 to 70 ft. below the surface of the site where the gas works were to be erected; yet that bill was passed. When our legislators seemed to so little understand these questions of the importance of the purity of a water supply, and the great danger which is likely to arise from pollution, either in the distribution of the supply or the injurious properties which may be imported at its source, they could not be surprised that there were so many small communities throughout the country which did not regard the question of the water supply from any favorable point of view. They looked upon engineers who advised them that the purity of a water supply was a paramount necessity as having a crotchet, and very often said, "Well, the supply was good enough for our fathers, surely it is good enough for us." That was the answer given to any question as to the pollution of wells which exist pretty well in all the villages and towns of this country. It

was, however, a great question, and they were indebted to Mr. Middleton for having brought the matter under their notice so clearly and concisely. Of course, some watershed areas were very large, like that of the Thames, others were of comparatively small area. Wherever he had anything to do with the formation of districts, he had always drawn the boundary at a watershed line; but where watershed areas pass through two or more counties they were met with great difficulties. For they were told under recent Acts it was almost impossible to take part of a district which belongs to one county and put it under the jurisdiction of a sanitary authority which principally governs in another county. That, however, had been done recently in a case where a district had been taken out of one county and put into another, and he did not see that what had been done in that small way could not be done to a very large extent throughout the country. There was no reason whatever why they should confine themselves to the present arbitary boundaries. A watershed area formed a very good natural boundary, certainly for drainage purposes. The difficult question was in regard to the large areas—an authority to pass over nearly 6,000 square miles in the Thames area would be a sort of legislative body in its government of such a large part of the country. But there was no doubt the principles of watershed areas should be kept in view in the formation of all new districts, and not so much as had been the old boundaries of parishes, which were not properly defined, or served any useful purpose in regard to the engineering work to be carried out within the district they made. It was therefore a question which needed full investigation.

Major Lamorock Flower (London) observed that he was very much obliged to Mr. Middleton for having brought forward this old idea of his of treating the watershed area as the proper boundary for a sanitary district, and he was equally glad that Mr. Baldwin Latham had drawn attention to the absolute absence of control over subterranean supplies. He contended that no Conservancy Board is complete which has not control over the subterranean water. At the present moment there was no Conservancy Board, nor was there any authority beyond the common law which had any power to prevent the pollution of subterranean water. With regard to the division of the country into watershed areas, it was

no doubt surrounded by a vast amount of difficulty, but a Vice-President of the Institute, Sir Francis Powell, had introduced into his Rivers' Pollution Bill of this year a clause which provided for committees to manage this very question — committees to be formed out of the existing County Councils. It has been said that if the watershed area was made the boundary of jurisdiction it would create a new authority, but he contended that no new authority was necessary at all. It was simply a combination of certain portions of the existing authorities for definite purposes, and therefore he thought the question of dividing the country into watershed areas for the purpose of preventing pollution of water was an exceedingly simple one, and only required to be thoroughly thought out by people who know what they are about to be carried into effect. He did not allow the word "impossible" to be in his vocabulary, for nothing in reason was impossible, and he did not see why this idea could not to be carried out thoroughly and entirely. He believed that the chairman, with his large knowledge and valuable experience, would be able to support the idea so ably brought forward by Mr. Middleton.

Dr. A. Haviland (Farnborough) agreed that they were indebted to Mr. Middleton for having brought forward this subject in the able way he had done. The chairman might remember that more than twenty-seven years ago, when he (the speaker) first commenced his investigations with regard to the geographical distribution of disease in England, he had made the remark in his first work that a natural system should be adopted instead of the artificial one which now exists and defaces our maps of registration districts. There could be no doubt that unless the different areas occupied by the catchment basins of the different rivers and their tributaries be under control, and so managed as to be capable of doing good instead of harm as at present, statistical accuracy was impossible, because there were conflicting interests in one registration district. If a natural system were adopted they would know exactly how to apportion their statistics, and would be able to see what watershed areas ought to bear the burden of disease that their polluted waters engendered. In fact, it was the only scientific method of using the statistics to anything like good purpose. Those who had followed the reports of the Commissioners appointed to investigate into the

pollutions of rivers would remember the excellent map of the Thames basin which the chairman (Mr. Symons) brought forward in his evidence. Lately he had had occasion to compare that map with its natural boundaries of the water partings with the boundaries of the registration districts, and if they were to see how thoroughly opposed to anything like reason those registration district boundaries were, they would be at once convinced of the abnormity of the whole affair, and wonder how in this nineteenth century such a state of things could be permitted to exist. All catchment basins where floods are known to occur should certainly be under one authority that would be able to consider the best means to prevent those floods. Then, too, unless they had these natural boundaries it was impossible to show how certain areas conduced to certain climatic conditions, and those climatic conditions to certain diseases. Therefore from a medical and geographical point of view he certainly upheld the suggestion that the natural boundaries should be resorted to instead of the artificial boundaries. In France they had a much more natural system: they took the boundaries formed by the rivers for the most part and named the departments after the rivers. The Isle of Man was divided into certain sheddings which comprised certain parishes—about three or four in each; shedding means water parting, and those sheddings were marked out by the original inhabitants of the Isle of Man according to the catchment basins of the different rivers. It was remarkable how easy statistics were made for that island compared with what they are for England. As a student of medical geography, he could say that his experience from the very first in 1868 led him to conclude that we shall not arrive at anything like what we want to arrive at—scientific fact—unless we had a natural system of boundaries.

The Chairman (Mr. G. J. Symons) pointed out that the delivery of compensation water had been fought a great deal, as to whether it should be sent down during working hours or whether it should be sent in a continuous flow. It seemed to him that it did not matter much what was put into an Act of Parliament, because all depended upon how big the lodge is at the top mill on the stream. If the top miller had storage for twenty-four hours' supply he could just please himself, he was master of the situation;

and half a dozen Acts of Parliament could not prevent him. The County Councils, especially the Yorkshire Council, had taken a great interest in the matter and he was not saying one word against them. All wished that to be done which is best, but it seemed to him that the occupier of the top mill was monarch of the situation. Then there was the question of floods which had so many conflicting points. The ordinary sanitarian and the ordinary Britisher had a great idea that a flood is a nuisance, and a thing that ought to be avoided. In a great many instances farmers rather enjoyed them than otherwise, and instead of getting the sympathy of farmers in their attempts to prevent them they got the other thing. He thoroughly agreed with Mr. Latham in his remarks about the pollution of underground water, but he was surprised to hear him say that he thought that all the principal epidemics of typhoid were traceable to underground water. His own impression was that a good many of them were due to milk. In his own neighborhood there was one such case, and he had heard of many instances arising in the same way. As to the rectification of county boundaries he was rather amused at one thing. Mr. Middleton had brought the question forward, Major Flower claimed to being its father, and somebody else had suggested Mr. Haviland, while in former times it was an idea which he (the chairman) had. So it must be right as they all had chosen it. But the question was, how was it going to be carried out? One of the disadvantages of living in an old country like England and Wales, was that things were crystalized for so many years, before watersheds were thought about. He did not know how their ancestors selected the county boundaries, but water partings had next to nothing to do with it. He did not attach serious weight to the difficulty of dealing with large areas, like the Thames and some of the other rivers, say, the Severn, because he could see no reason why they should not be cut up into subsidiary ones, and then be perfectly manageable. The difficulty was their being in a very old country where it was difficult to move. There was such a number of vested interests in the way. Mr. Latham described one bit of good work in which a part of a county was chopped off and transplanted into another, and probably hardly anybody knew anything about it till it was done. In Scotland he was glad to say the same process was going on. The Scotch counties were formerly distributed in a way that

made them very worrying to a school boy, and now nearly all those detached portions were being transferred by some Act of Parliament, and gradually absorbed by the counties in which they were situated. Like everyone else he had thoroughly enjoyed Mr. Middleton's paper and did not know that he had any criticism to answer, for there had been nothing but praise.

Mr. Middleton, replying to some of the points raised, said he was obliged for the way the paper had been received. He did not pretend to be one of the fathers of the idea at all, for he thought it was older than he was, but it was one of the old things which was none the worse for a little keeping—which must be impressed upon people over and over again. As the chairman had said, this was an old country and required a good deal of stirring up to get alterations, especially in matters of sentiment. Up to recently, the boundaries between counties had been questions affected by sentiment—the people of Suffolk looked upon a Hampshire man as a foreigner who did not belong to the same country at all, and there were parts in the north where a Londoner would not understand what the people were saying. But steam locomotion had largely changed that, the rapid travel of today was producing a still more rapid change in the country at large. Sentiment was largely dying out, though there was a sort of attempt to maintain it in the territorial regiments, but he did not think that had been very successful so far. As time went on it would be more easy than it had been in the past to get people to see that the boundaries between counties had in some cases been mere matters of sentiment, and that a great many of them could be improved very much, not only with advantage to the inhabitants themselves, but with still greater advantages from a sanitary point of view. There could be no question that the present divisions were injurious to many sanitary schemes and water supplies. It was often impossible to carry out a good scheme to prevent the pollution of water, because one of the parishes thought it was not the right thing to do, or sewage had to be discharged from one parish into another, where there was opposition. With regard to the size of the area, they now had the Thames Conservancy which had been given a certain amount of power over the whole of the watershed area of the Thames, which covered some 6,000 square miles. He did not say that the power

which was put into the hands of the Thames Conservancy was a sufficient power, though it was considerable, and would have a great influence on the future of the Thames basin. One of the greatest difficulties, both in regard to the Thames Conservancy and any other Conservancy or Council for the conservation of the watershed of any river, was the question of funds. The Thames Conservancy were fortunately able to get a considerable amount from the London Water Companies, and a great deal of their work which was done for the benefit of London in the way of keeping the river pure for the supply of that city, was done at the cost of the water companies. But in most other places there was no fund available for the use of the Conservators of the river, and the rate-payers strongly objected to be rated directly for any such purpose. Those below said they were only flooded every now and then, and that it was not worth while; those higher up were not flooded at all, and did not think they were the ones to pay for the benefit of those lower down. The only way out of the difficulty was for the whole district to pay and the rate would be so infinitesimal that it would be scarcely calculable, nobody would feel it at all. Some means of that kind would have to be found for providing sufficient funds for preserving rivers from pollution, and also in regard to the almost equally important question of flooding. Up to lately the Thames had suffered in some cases greatly from floods. Not many years ago Taunton suffered from a serious flood, which was all the worse because timber happened to be stored beside the river and stuck in the bridge, with the result that the lower part of the town was flooded to a considerable depth. Taunton was then going to do many grand things, but they eventually did nothing. In other parts identical cases could be quoted, and he supposed the periodical floodings would continue until they got some such Board as he had mentioned. It was true that farmers on the banks of the rivers liked their land occasionally flooded, but not to any great depth, for they did not care to have their fences washed away or anything of that kind. But if it was a flood which passed two or three inches over the land and left a sediment behind, they did not mind. This, of course, could not always be provided for. If they were approached immediately after a flood of 5 or 6 ft. they would be quite ready to pay for their prevention. Apart from that, the farmers were not the people to

be considered, because it was not the farmers only who suffered from floods but the people in the towns and villages, sometimes seriously, both in pocket and comfort. The difficulties in the way of providing a proper authority were very great. He did not think an amalgamation of the Councils for such an area as the Thames would be satisfactory, for it would simply mean a shifting of responsibility and liability, the same people would be concerned, who, if they met at separated Councils would only fight still more. He did not think that would be a good and final representation, but what would be the best representation he was not prepared to say at the present moment.

ABSTRACT FROM THE REPORT TO THE EXECUTIVE BOARD, ROCHESTER, N. Y.

BY E. KUICHLING, CHIEF ENGINEER OF WATER WORKS.

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THE OLD CONDUIT.

The old conduit from Hemlock Lake to Mt. Hope reservoir was constructed during the years 1873, 1874 and 1875, and is divided by the storage reservoir at Rush into two principal sections. Excluding the 36-inch intake pipe at the lake, the first or southern section embraces 50,807.3 ft., or 9.623 miles, of 36-inch wrought-iron riveted pipe made of plates 3-16-inch thick; 15,446.5 ft., or 2.925 miles, of 24-inch wrought-iron riveted pipe made of plates 3-16 and 1-4-inch thick; and 36,009.9 ft., or 6.820 miles, of 24-inch cast-iron pipe of varying thickness, according to the water pressure; total length = 102,263.7 ft., or 19.368 miles, from the mouth of the pipe in the gate-house at Hemlock Lake to its end in the submerged influent well of Rush reservoir. * * * * *

The discharge of the old conduit was gauged twice last year at Rush reservoir, the first measurements being made on June 22–24, and the second on November 9–10. Owing to the failure of securing means for completing the permanent connections of the conduits with the two reservoirs, it is still necessary to make all such measurements in a very tedious manner by carefully observing the rise or fall of the water service in Rush reservoir, as well as the evaporation therefrom, during a period of eight hours or more, and then ascertaining the rate of leakage of the reservoir as soon as possible afterwards. In the southern division of 19.368 miles, from the lake to Rush, the delivery of the pipe is determined by the rise of

the water in said reservoir after closing all outlet valves therefrom, while in the northern division of 8.879 miles from Rush to Mt. Hope, it is determined by the fall of the water surface caused by the relatively greater discharging capacity of the northern portion of the conduit, as it is not deemed expedient to subject the southern division unnecessarily to full hydrostatic pressure by closing the inlet valve.

The results of these complicated gauging operations were as follows: On June 22–23, during a period of 22.5 hours, and on November 9, during a period of 5.5 hours, the discharge from the southern division was at the rate of 6,598,400 and 6,675,900 gallons per day respectively; while on June 23–24, during a period of 22.25 hours, and on November 10, during a period of 8 hours, the discharge of the northern division was at the rate of 7,887,800 and 8,153,400 gallons per day respectively. Comparing these figures with the similarly observed discharge of 7,185,000 gallons per day for the southern division on October 10, 1890, and that of 8,392,700 gallons per day for the northern division on September 25, 1892, a very marked reduction of delivering capacity, amounting to about one per cent. per year on the average, will be noticed in both divisions, which is probably the result of accumulations of rust, sediment and organtic growths on the interior of the pipe. A further comparison can also be made with the gaugings of the southern division, made early in 1876 by the late Mr. L. L. Nichols, C. E., which then exhibited a discharge of about 9,000,000 gallons per day, thus showing that such reduction has been progressive or continuous during the whole period of twenty-two years. Owing to lack of reliable data, no good estimate can be made in regard to the future rate of this diminution of flow, but from such observations as have been made here and elsewhere, it is very probable that it becomes smaller each year, instead of increasing.

THE NEW CONDUIT.

The new conduit from Hemlock Lake to Mt. Hope reservoir was constructed in 1893 and 1894. Excluding the intake pipe and gate-house at the lake, it consists of a brick conduit of horseshoe-shaped cross-section, 6 ft. high and wide inside, and 11,892 ft., or 2.252 miles long, terminating in an overflow chamber 34 ft.

long, the north end of which forms the beginning of a 38-inch pipe conduit 138,260 ft., or 26.186 miles, in length to the new gate-houses at Rush and Mt. Hope reservoirs. Of this latter length, 136,948 ft. is 38-inch riveted steel pipe made of plates $\frac{1}{4}$, $\frac{5}{16}$ and $\frac{3}{8}$-inch thick, and 1,312 ft. is 36-inch cast-iron pipe and special castings distributed at various points. These distances are measured along the axis of the pipe from its beginning near Hemlock Lake to the middle of the by-pass branch casting in the new gate-house at Rush reservoir, thence to the middle of a similar casting in S. Clinton street near Elmwood avenue, and thence to the east face of the foundations of the new gate-house at Mt. Hope reservoir; the additional lengths of pipe and castings laid beyond the said branch in S. Clinton street, and also in the two gate-houses for reservoir connections, are therefore not included in the above figures. * * * * * * *

The gaugings of the discharge of the middle or second section of the new conduit, to which reference was made in the Report of the Executive Board for 1896, were repeated last year; and as such reference contains several numerical errors, advantage is taken of this opportunity to correct them. The observations were carried out essentially for the purpose of determining the discharge at different degrees of opening through the 8-inch by-pass valve of the main 36-inch inlet valve at Rush reservoir, this being the means by which the flow into said reservoir is temporarily regulated, owing to the failure of an appropriation for completing the permanent connections. In these operations, the rates of discharge and velocities through the conduit were computed from the observed rise of the water surface in the reservoir during considerable periods of time, with due allowance for evaporation and leakage, as determined separately; and the corresponding losses of head by friction in the conduit were deduced from the observed heights of an open column of mercury, which was connected with the conduit at the reservoir, in comparison with the approximately measured elevations of the free water surface in the vertical 24-inch overflow stand-pipe at West Bloomfield, which is 46,338.76 ft., or 8.776 miles distant from the point of attachment of the mercurial gauge. Proper corrections for temperature were also applied to said heights of mercury, and the difference in level between the zero of

the gauge and the point of reference at the top of said stand-pipe, was subsequently determined as accurately as possible by means of the height of the column of mercury, after the inlet valve at the reservoir and the main stop-valve in the conduit south of said stand-pipe had been completely closed, as described above. The principal results obtained in 1896 and 1897 are given in the following table :

No. of Experiment.	Date.	No. of turns opening of 8 in. by-pass valve at Reservoir.	Duration of Experiment. Hours.	Observed rise of Water in Reservoir. Feet.	Observed loss of head (h) in length of 46,339 ft. of 38-in. steel pipe. Feet.	Computed Velocity (v) in 38-in. steel pipe. Ft. per sec.	Computed Coefficient (c) in Chezy Formula: $v=c\sqrt{rs}$.
1	June 9-10, 1896	8	12.76	0 31863	1 562	0.48948	94 75
2	" 10-11, "	10	13.61	0 40274	2.353	0 61180	96.49
3	' 14-15, "	12	11.40	0 41142	2.804	0.75794	109.51
4	" 14, "	14	8 08	0.33600	3.755	0.88754	110.81
5	" 13-14 "	16	12 35	0 57792	5.790	0 96469	96 99
6	" 12-13, "	18	11.99	0 61377	5.818	1 05830	106 15
7	" 12, "	20	4.18	0.22708	6.093	1.13004	110 76
8	" 12, "	22	4.98	0 28315	6 559	1.18723	112 15
9	" 11, "	26	4 18	0.25569	7 688	1.26459	110 34
10	Oct. 9, "	26	8 52	0.49739	8.391	1.22263	102 12
11	July 6-7, 1897	26	15.87	0.95799	7 553	1 23897	109 07
12	" 7, "	24	10 57	0.62524	7.159	1.25425	113.41
13	" 9, "	22	9 03	0 53824	6.571	1.22286	115.41
14	" 9-10, "	20	13 82	0.77871	5 697	1 15065	116 63
15	" 10, "	18	8.97	0 49900	5.431	1 10751	114 98
16	" 14, "	16	8.95	0 43968	4 858	1 02060	112 03
17	" 14-15, "	14	14.90	0 64108	3.793	0 89790	111 53
18	" 15, "	12	7 75	0 29226	2 850	0.81413	116.49
19	" 15-16, "	10	14.50	0.43561	1 841	0.63742	113.66
20	" 16-17, "	8	13.62	0.32566	1 179	0 50525	112 58

Mean value of coefficient for observations Nos. 1 to 10 inclusive, 105 01.
Mean value of coefficient for observations Nos. 11 to 20 inclusive, 113.58.

It should be distinctly noted that the observations made in 1896 for the loss of head in this section of the conduit, in connection with the gaugings mentioned, were only approximate, whereas those of last year (1897) were made with the utmost care. The latter are therefore entitled to much more weight than the former. Moreover, no good reasons can be given for the incongruities in the values of the coefficient (c) for the series of experiments in 1897,

which are exhibited in the foregoing table, and the results are submitted without further comment, except that they emphasize the necesssity of adopting the greatest refinement in making such measurements.

Other gaugings of the full capacity of the new conduit, with the existing temporary reservoir connections of 16-inch cast-iron pipe, were also made during the past year, the details of these operations being the same as indicated above for the old conduit. The southern part of the line, from the end of the brick conduit near the village of Hemlock Lake to Rush reservoir, consists of 91,553.61 ft. of 38-inch riveted steel pipe, and 93.60 ft. of 36-inch cast-iron pipe, valves and special pieces, thus giving a total length of 91,647.21 ft., or 17.357 miles, between points of observing loss of head; while the northern part extends from Rush reservoir to Mt. Hope reservoir, and consists of 45,393.93 ft. of 38-inch riveted steel pipe and 1,218.35 ft of 36-inch cast-iron pipe, valves and special pieces, or a total of 46,612.28 ft., or 8.828 miles, between points of observation. In this northern division, the greater part of the 36-inch cast-iron pipe is located in a continuous stretch at Rush reservoir, arrangements being made to observe the loss of head therein separately from open piezometers. It should also be noted that near the city the line makes an abrupt turn of 90 degrees, as it was intended to continue the direct line to the contemplated new distributing reservoir on Cobb's Hill.

In computing the value of the coefficient (c) in the Chezy formula $v=c\sqrt{rs}$, from the observed data, the influence of the few short sections of 36-inch cast-iron pipe and special castings in the southern division has been disregarded, and the line is treated as a continuous pipe with a uniform internal diameter of 38 inches, this being the diameter of the "inside" courses; but in the northern division, the quantity of such cast-iron pipe is large enough to warrant its separate consideration, along with the influence of the aforesaid square turn, valves and special castings, so that in this case trustworthy figures can be given for both kinds of pipe. The principal results of the various gaugings and computations which have been made on these two divisions, and which were recently revised with reference to the corrected altitude of Rush reservoir, are herewith submitted:

I. SOUTHERN DIVISION.

No. of Gauging.	Date.	Duration of Gauging Hours.	Observed loss of head (h), in feet in		Computed velocity of flow (v), in feet per second, in		Computed coefficient (c) in the Chezy formula $v = c\sqrt{rs}$. for		Computed Discharge in gallons per day.
			36-in. Cast-Iron Pipe.	38-in. Steel Pipe.	36-in. Cast-Iron Pipe.	38-in. Steel Pipe.	36-in. Cast Iron Pipe.	38-in. Steel Pipe.	
1	Oct. 4, 1895	4.96	None	91 053	None	3 2733	None	116 71	16,661,800
2	Dec. 23, 1895 ..	5 02	None	92 899	None	3.2308	None	114 05	16,445.800
3	July 23, 1897....	11 98	None	91 563	None	3 2482	None	115.50	16,534,400
4	Nov. 18, 1897...	7.43	None	91.398	None	3.1481	None	112.04	16,024,600

II. NORTHERN DIVISION.

1	Oct. 17, 1895....	5.35	*1.234	72.021	4.2040	3.8756	129.45	109 35	19,729,700
2	Oct 26, 1895 ..	5.22	†1.340	73 252	4.2386	3.9079	125 25	109 34	19,892,100
3	Nov. 7, 1895 ...	6 38	1.337	73 445	4 2340	3 9036	125 25	109 07	19,870,200
4	July 28, 1897....	10 77	2.026	73 766	4 1281	3.8060	99 22	106 11	19,373,400
5	Nov. 11, 1897....	7 92	4.287	69.521	4 0454	3 7297	66 84	107.11	18,985,100
6	Nov. 19, 1897.. .	7.08	4 318	69.609	4.0233	3.7094	66.24	106 46	18,881,700

*Obtained by mercury difference gauge.

†Determined separately; derived from computations made from the value of c(=125.25) found in succeeding Gauging No. 3.

The lengths of pipe between points of observation which were used with the computations in the foregoing table, are as follows: In the southern division, 91,640.83 ft. of 38-inch steel pipe; and in the northern division, 889.57 ft. of 36-inch cast-iron pipe and 45,393.93 ft. of 38-inch steel pipe. An examination of the last column but two of this table will also show that the friction loss in the stretch of 36-inch cast-iron pipe at Rush reservoir has increased greatly from July 28 to Nov. 11, 1897, probably in consequence of a profuse growth of organisms on the interior, similar to what was found in the old conduit at the same locality when the pipe was taken up for adaptation to the new conduit. That an error of observation was not made on the last-named date is proved by the repetition of the gauging on Nov. 19, 1897, which gave practically the same result. It is hoped that an opportunity to make a direct examination of the condition of its inner surface will be afforded during the present year. * * * * *

THE MOFFETT, HODGKINS & CLARKE COMPANY CASE.

In connection with the foregoing litigations, reference may also be made to the Moffett, Hodgkins & Clarke Company case, which has been pending in the United States Supreme Court since early in 1893, and finally came to trial last June.

This action arose from the failure of the Moffett, Hodgkins & Clarke Company to enter into contract, in January, 1893, for the construction of the new steel pipe conduit which had been duly awarded to said company by the Executive Board. Their proposal was accompanied by a bond in the penal sum of $90,000, which about 10 per cent. of the amount of the bid, conditioned that the bidder would promptly execute the contract and perform the work mentioned, if it was awarded to him. The Company, however, refused to accept the contract on the plea that a mistake had been made in their bid; and fearing that the board would attempt to recover the aforesaid large penalty, they immediately applied to the court for an injunction to restrain the city from declaring said bond forfeited.

It was alleged by the Company that a serious error had been made by their agents in writing in the accepted proposal the price of 50 cents per cubic yard for earth excavation in open trenches, instead of 70 cents as contained in a separate alternative bid for the same work if constructed along a different route for a portion of the distance; and as the total quantity of such excavation involved in the work was 184,000 cubic yards, they claimed that this error would entail upom them a loss of $36,800, if required to abide by their bid. On the other hand, a careful analysis of the bid established the fact that many of the other prices named by said Company were relatively high, and that while the proposal might be regarded as somewhat unbalanced, it was not sufficiently so as to warrant its rejection by the Board.

In the course of the trial ample evidence was offered by the city in proof that the contract could have been performed by said Company without loss, nothwithstanding their alleged error in the price for earth excavation; but the Court ignored the city's proof entirely, and singularly held that the mistakes in the bid were "clear, explicit and undisputed."

The following extracts from the decision cannot fail to be of interest to all municipal authorities :

"It would seem almost a reproach to our jurisprudence if equity be compelled to confess itself helpless in such circumstances. To grant the relief asked for does no injury to anyone. To refuse it entails upon the complainant a possible loss of $90,000; a penalty so out of proportion to its fault that its enforcement would seem repugnant to those principles of natural justice which are the foundation of all law." * * * "The law is based upon broad, general rules, applicable alike to individuals and corporations. A party dealing with a municipal corporation should not be held to the strict letter of his agreement where he would be released if dealing with an individual." * * * "If the defendants (the city) are correct in their contention, there is absolutely no redress for a bidder for public work, no matter how aggravated or palpable his blunder. The moment his proposal is opened by the Executive Board he is held as in a grasp of steel. There is no remedy, no escape. If, through an error of his clerk, he has agreed to do work worth $1,000,000 for $10, he must be held to the strict letter of his contract while equity stands by with folded hands and sees him driven into bankruptcy. The defendants' position admits of no compromise, no exception, no middle ground."

"It is argued that the mistakes were not mutual, and therefore that there is no ground of equitable cognizance. It should be remembered, however, that the complainant does not seek to reform a contract, but to be relieved from an unconscionable bid by its recission or cancellation. Equity cannot reform an agreement unless both parties were mistaken, but it can interfere to prevent the enforcement of an unjust agreement induced by the mistake of one." * * *

"It is said that the complainant has an adequate remedy at law. This objection does not appeal strongly to the Court in a case where all the parties are on the record, where all the facts bearing upon the transaction have been collected with great diligence and expense, and where the questions in dispute have been fully and ably debated. In such circumstances the Court should not, unless clearly compelled to do so, adopt a course which will render nugatory all this labor and expense. Believing that the complainant is entitled to relief, the duty of granting it should not be devolved upon another tribunal in order that a doubtful theory may be vindicated." * * *

"The complainant is entitled to a decree rescinding its proposals, and enjoining the defendants as prayed for in the bill."

While it may not be in good taste for a layman to criticise the findings of a high tribunal, it is nevertheless fair to the officers of the city to say that the proof of their side of the case was so strong as to make it impossible for them to admit the full justice of this decision. By the failure of the Company to execute the contract and the award of the work to the next bidder, the city sustained a loss very much larger than the amount of the bond, which circumstance seems to have been entirely overlooked by the judge when he stated that the granting of the relief asked for by the Company did no injury to anyone. The fact is that a large burden of additional expense was thereby placed upon the taxpayers of this community, and it is also a fact that many other courts have held that a mistake of the kind which is alleged to have been made cannot free a bidder from responsibility therefor.

If this decision is a sound one, then the practice of advertising for proposals for the performance of public work becomes a simple farce, and all charter provisions which require the executive officers of municipalities to advertise for proposals can only have the effect of imposing unnecessary expense upon the taxpayers, and of inviting fraudulent collusion between bidders after the proposals have been opened and read. It will then be extremely easy for a high bidder to induce the low ones to allege that they had made a mistake in their figures, and as the bonds which they may have given as evidence of good faith on their part can readily be declared void by a court, a municipality can be mulcted to untold extent by being compelled to have its public work performed at excessive prices. From the standpoint of sound public morality, it does not seem possible that the broad road which has thus been opened to dishonorable practice by contractors can be maintained, and an appeal from this decision has accordingly been taken.

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ABSTRACT FROM THE REPORT OF THE DEPARTMENT OF PUBLIC WORKS, ST. JOHN, N. B.

BY WM. MURDOCK, ENGINEER AND SUPERINTENDENT.

* * * * * * * * * *

The Common Council having passed an order on the 17th day of June directing that the mains leading from Little River Reservoir to the city be cleaned, preparations were at once begun to carry out that order.

As there were no hatch boxes laid in the original construction of the lines, drawings and specifications had to be prepared, and on August 6th a contract was awarded to Mr. James Fleming to cast eight hatch boxes for 24-inch pipe (afterwards increased to nine) and four hatch boxes for 12-inch pipe as well as all the requisite sleeves at the rate of two cents per pound. Excavating was commenced at the reservoir for placing the boxes on leading mains Nos. 1 and 2 on September 11th; the first hatch box was delivered on October 1st, and the main was cut and hatch box inserted October 6th.

Advantage was taken of this opportunity to remove the old receiving chamber which connected mains 1 and 2, and of extending No. 1 main up to the receiving chamber placed in the year 1873, when No. 3 main was laid. At that time this chamber could not be removed without stopping the city's supply; so it was left in. This extension was made and the 12-inch hatch box placed October 7th.

Cleaning water mains having never been attempted here before and the business being new, particular pains were taken to prevent any mishap. In designing the cleaner or mechanical scraper special precautions were taken to avoid the misfortune of having it lodge in the pipe with such consequent vexatious searchings, and cuttings of pipe as have often occurred elsewhere. The desiderata laid down were:

(*a*) That the apparatus be as light as possible, so as to be easily projected up ascending gradients by the pressure of the water and

to offer generally as little resistance as possible, whether through inertia or otherwise :

(*b*) That as it is more desirable to take light cuts and make frequent runs than attempt to remove all the dirt at once and have the scraper stick, therefore the pistons should be so loose as to permit a free escape of water to carry off the loosened dirt in advance of the cleaner, and that the arms be not so rigid as to hold it up against any hard and abrupt obstructions encountered.

With these maxims in view, the machine was made as shewn in the accompanying illustration,* the pistons being of birch set in layers, each layer being one inch in thickness and placed crosswise of the other to prevent warping, and increase the strength of the piston. Leathers were secured to the piston by means of an iron ring bolted against them, the bolts being run through the piston.

The spindle connecting the two pistons is of 3-inch wrought iron pipe with a cast iron flange screwed on each end and pinned over with a hammer to prevent the screw backing out. These flanges are each bolted through the pistons to another flange on the opposite side.

Projecting beyond the forward piston is an iron rod fitted with two sets of radial arms sloping back as shewn in the cut. There are four arms in each set, made of No. 10 (B. W. G.) spring steel 2 inches wide and each fitted with a forged steel scraper on the end, of the form shewn in the accompanying illustration. The long sloping fish-tail form of this scraper enables it to glide safely over every obstruction.

In making the first runs only one set of scrapers was attached, but in the latter the whole eight were in use. This precaution was taken lest a large amount of dirt should be loosened at once and the cleaner become buried and stop.

On October 12th, No. 2 hatch box was placed on No. 2 main at Hickey Road, a distance of 6,000 feet from the reservoir and at 1 p. m. the same day the work of cleaning began.

The head of water upon the upper hatch box was 20 feet and on the lower 27 feet. The first run took four hours, for the reason that a cord sufficiently long to reach the whole length had been placed on a revolving drum 10 feet in circumference and furnished

*The illustration is omitted for want of time to reproduce it.—EDITORS.

with an indicator to register the revolutions. The end of this string was attached to the drum and a record kept of its location as it sped along. But when the first flushing branch was reached the twine drifted out here and down the brook while the drum kept on revolving and the indicator registering until the whole string was paid out. Meanwhile the cleaner had become securely moored near the flushing branch and could not be liberated until the stopcock was dug to and uncovered. On the twine being cut and pulled out and the stopcock lid restored, water was let on again and the cleaner finished its journey, a distance of 2,200 feet, in about five minutes.

This first run was sufficient to shew that twine was dangerous; and we also learned that it was entirely unnecessary, for the grating sound of the cleaner as it passed through the pipe was heard quite distinctly by the two watchers, under their feet as they followed the sound along the line.

Two more runs were given that same afternoon, the time occupied to go the distance being about twenty minutes.

The water was inky black for some time as it flowed from the flushing pipe and it was allowed to run for two hours after the cleaner had been removed, this time having been required for the water to clarify.

The next section was taken on Saturday, October 23d. It extended about 6,600 feet cityward, but in order to give the first section another scraping it was concluded to insert the cleaner at the dam and run it through the entire 2.4 miles.

A misfortune was met this time in the following manner: The leathers having worn out during the first cleaning, they were renewed with a harder and stiffer quality than before, but they repeatedly caught in a new joint made while inserting the hatch box. Each time the lid was removed to ascertain why the cleaner did not start it was found firmly fixed by this imperfect butt of the two pipe ends. After twice extricating it and again finding it caught in the same way, a jack-screw was applied to push it past this obstruction, the lid was again put on and the water let in at 4.05 p. m. This time it started. At each of the five flushing stations the gate was left open fully ten minutes after the cleaner had passed and then closed. As soon as the gate was closed the cleaner again proceeded and the scraper *with only one piston* reached the end of its run at 5.25 p. m., having been one hour and twenty

minutes going 2.4 miles, but when the fifty minutes of total stoppages are reckoned, the machine was found to have been in motion thirty minutes.

As stated, only the forward part of the cleaner arrived, and search had to be made for the remainder. Nothing was done on the following day, which was Sunday, the castaway piston which was lying obliquely somewhere in the pipe having but partially obstructed the flow, and the water was left on till the Monday night following.

A receiving chamber unites Nos. 2 and 3 mains near No. 3 hatch box and they are controlled by stop cocks on each side of the receiver. It was, therefore, an easy matter to reverse the current of water in No. 3 by closing the stop cock at the dam, and opening that at the receiver as well as the flushing branches. This was done, and men were distributed along the line to listen for a rumbling noise, which at length was heard about one-quarter mile of hatch box No. 3 from which the cleaner had been extracted. The sound was followed along the line toward the reservoir until hatch box No. 2 was reached when the derelict was taken out, after having travelled nearly a mile and crossed a valley about 90 feet in depth. It was found that the pressure of the jack-screw in forcing the cleaner past the uneven joint had cracked one of the flanges, with the result that after having travelled 2¼ miles the cleaner fell apart. The forward part comprising a piston and the scraper, pushed on, but the spindle attached to the rear piston fell to the bottom of the pipe, ploughed up some dirt and finally imbedded and jammed. The reverse current striking the piston as it did, drove it back, with the spindle trailing behind.

The apparatus was repaired and three more runs made through this double section of 12,600 feet, on October 27th, without any further mishap, the time taken for each run, including a ten minutes stoppage at each of the five flushing stations having been one hour and forty minutes to two hours and thirty minutes. The cold weather being on when the next casting arrived, cleaning operations were suspended for the season, to be resumed next spring.

On testing the efficiency of the cleaned main by shutting off No. 3 from the reservoir to the receiving chamber where both unite, and bringing the supplies through Nos. 1 and 2, it was found that the pressure in the city was as good as when No. 2 was

shut and the whole supply coming through Nos. 1 and 3, thereby showing that the capacity of No. 2 had improved to such an extent that when with No. 1 it had formerly delivered to a height of 80 feet only, when unassisted by No. 3, and left 200 acres of the city containing 8,500 inhabitants without water, now the whole city could be supplied without the help of No. 3 and the water rise to a height of 130 feet above high water. The general improvement in pressure with all the mains on was found to be about four feet.

Nearly two miles of this line remain yet to be cleaned, after which the other two pipes will be taken as soon as the coming season permits. * * * * *

ABSTRACT FROM THE REPORT OF THE WATER COMMISSIONERS, TROY, N. Y.

BY WILLIAM G. RAYMOND, ENGINEER.

* * * * * * * * * *

DAMAGES TO MILL POWERS.

It has been said that every dweller along a stream has a common law right to have that stream continue to flow as it has ever been accustomed to do. This is true. But the law also provides that a municipality may take a portion, or all, of the water of the stream for public use, provided it pays the dwellers along the stream who may be affected by the diversion of the water, suitable sums of money as damages.

The determination of these sums is usually entrusted to a commission acting under the authority of a court. The awards made by such commission may be appealed from to the court.

It will readily be understood that it is absolutely impossible to predict what any commission will judge to be the damage sustained by each of the individuals affected by the diversion of the flow of the stream. It is, however, possible to make an estimate of what will be a fair and reasonable allowance. There are many considerations that enter into such an estimate, and it is not a simple matter to arrive at the conclusion.

In the cases of the Quackenkill, Poestenkill, or Tomhannock streams, it is safe to predict that the damage sustained by the farmers along the streams, who have no mill powers, will be nominal, since not all the water will be diverted, and enough will be left for the watering of stock, and similar farm uses. Moreover, some of these dwellers will be distinctly benefited by a lessening of the spring flood water.

I have on former occasions stated in an informal way, that the methods of arriving at the damages to be awarded the owners of mill privileges for the diversion of a part or all of the flow on which they depend for power have changed in recent years. This statement has been questioned. I wish to reaffirm what I have said on this subject. So far as I know the law has not changed, but the method of determining the measure of damage has changed.

The following method has prevailed in the past:

A city proposes to build works that will enable it to draw ten millions of gallons of water daily from a stream. Below the point of diversion is a mill power with twenty feet of fall or head. The miller claims that ten millions of gallons daily over twenty feet fall means thirty-five horse power, good the whole twenty-four hours; or by storage in his mill pond it is good for eighty-four horse power for ten hours daily. At his particular location, out in the country, coal is high, and he estimates that it will cost him, including interest, sinking fund, repairs, fuel, oil, attendance, etc., $60.00 per horse power per year for ten hours daily. Eighty-four horse power would then cost $5,040 per annum. This sum capitalized at six per cent. gives $84,000 as the damage to him for the diversion of the water. He may not be quite so grasping as this, and may admit that his plant is built for only fifty horse power, and that this is all he can use, and that this is what will be destroyed, and hence he asks payment on the basis of fifty horse power, Damages have been awarded on just such estimates as these. It will be observed that no account has been taken of any one of the following points, one or all of which may be pertinent to the particular mill in question:

I. The same reason that makes coal high makes the cost of hauling raw material and finished product high. The miller could operate to better advantage in some other place.

II. His business does not demand eighty-four horse power nor fifty horse power. The unutilized power is certainly not of the same value as that that is used.

III. He needs steam for heating, and possibly also for manufacturing purposes, necessitating the maintenance of a boiler plant. Exhaust steam from an engine will do as well for these purposes. thus reducing the cost of steam power,

IV. The stream is irregular in flow so that to keep up regular power he has been already obliged to install a steam plant. Interest on first cost, a large portion of the repairs and the cost of running for the average time now run should not be chargeable to the city.

V. The stream is irregular, and the mill pond is not large enough to permit the use of the full supply, and perhaps not to give fifty horse power at all times. The power thus wasted should not be charged to the city.

VI. The flow of the stream is irregular, and throughout a con-

siderable portion of the year it is less than ten millions of gallons daily. Only the actual flow stopped should be considered for this period.

VII. The flow of the stream is irregular, and during a considerable portion of the year the flow is so great that the power that it is feasible to develop at the mill will not be in the least lessened by the water taken by the city. For this period no damage should be claimed.

VIII. It costs something, singular as it may seem, to develop water power. Only the difference between the cost of operating by water and steam should be considered. It is true that some of this cost of water power, such as the interest on cost of dams and reservoirs that must go on even though steam be substituted for water, can not be offset in this way.

IX. The average run of water wheels do not develop more than two-thirds of the theoretical power of the water, and the very best do not average more than three-fourths throughout the year. It is clear that no more than this should be charged as net horse power.

X. Last but not least, the business that the miller carries on yields him a net revenue of not to exceed $1,000 annually, and so far as it appears he is getting all out of it that can be gotten. Is he to be paid five times the value of the business for destroying a part or even all of it?

In the past many or all of these considerations, favorable to the city, were omitted in the estimation of the measure of damage. Today they are considered, together with some other items that are favorable to the mill owner. Different considerations arise for different powers. The single item of transportation has come to mean much more than it once did. Moreover, the laws of trade are such that a manufacturer can not make up a great quantity of goods when power is plenty and hold them till called for. He must run when he gets the orders, and this may be when there is no water to run with. These considerations have done much to lessen the value of power on irregular, small streams. This is evidenced by the number of mills on such streams that have been abandoned as worthless. On the Tomhannock there were formerly a number of mills, flax mills, paper mills, cotton mills, powder keg factory, etc. Now there is practically nothing left of all these; two or three country grist and saw mills being all.

Coming now to a consideration of the streams near Troy we may estimate somewhat as follows ;

The assessed value of the less important country privileges that will be affected is about $12,500, The country assessments are very uncertain as to their relation to true value. Assuming that they represent half value, it would require $25,000 to purchase them all.

Exclusive of these powers treated in this way, there are other more important powers in the country and city having an aggregate head available of about 280 feet. Each million of gallons daily over this head, assuming it to be well developed is equivalent to about 49.1 horse power throughout the twenty-four hours. Many of the plants run but ten hours, and others run twenty-four hours when there is water to run. With a single exception all of the more important powers are already supplied with steam power. Very few water powers are maintained for less than $8.00 to $12.00 per annum per horse power. We will assume $10.00 in these cases.

Twenty-four hour power can be furnished by steam to most of these mills for not to exceed $98.00 per annum per horse power. Add the cost of the interest on the steam plant, the cost of operating a portion of the year, and a part of the sinking fund, etc., to the cost of maintaining the water power, and the difference between water and steam power on these streams will not be more than $38.00 per annum per net horse power. Some of the mills use water in considerable quantities for manufacturing purposes and due allowance should be made for this.

Ten millions of gallons over a total head of 280 feet will represent about 491 twenty-four hour horse power. With an efficiency of 75 per cent. for the wheels, a difference of cost by steam or water of $38.00 per net horse power, and interest at six per cent., there results a gross valuation of the damage arising to these mills—assuming the diversion of the water to affect them continually—of $233,225.

There are from four to six months during which the flow is so great that, according to some of the mill people themselves, our diversion of the water of the upper portion of the watershed will not affect them in the least. There are several months of the year during which the flow of the stream is not ten millions of gallons

daily, when indeed, including the flow of the upper storage ponds, it will not exceed four millions daily. Assuming these facts the damage reduces to less than $100,000 after adding the cost of purchasing the country mills. To take eighteen millions daily will on this basis cost less than $160,000. It will be many years before this amount of water is required, and hence the present value of the damage should be less than these sums. It should be the amount of the present damage added to a sum which placed at interest now will equal the estimated future damage by the time the future damage will be sustained.

It is thus seen that the estimate of $125,000 made some years ago is not so far out of the way. The damages actually awarded may of course exceed this amount. It is only an estimate, based on the powers as a whole. But it should be said that a number of these powers heretofore considered important have been idle for a number of years.

It is well to form some idea of the probable cost of such a work as this is before undertaking it, but the best that can be done, unless you desire to settle with these owners on their own terms, is to make an estimate based on the facts known, and on experience elsewhere when details for the case in hand are not available. It is therefore proper to note that in a number of recent cases the awards of the commissions have been somewhat singularly about ten per cent of the claims of the owners. It is of course well to consider these claims of owners, but what sane man would use this as a basis of settlement? And what owner expects that it will be so used? It is worthy of note in this connection, that in the case of Syracuse, the awards were almost exactly one-tenth of the claims. It is but right to say that these cases are not all finally settled.

Inquiries sent by me to the various owners of privileges along the Poestenkill and Quackenkill have been answered sufficiently to enable me to estimate the probable amount of claims at $400,000.

It is interesting to note in this connection that the entire assessed valuation of all the mill privileges on both streams, from the mouth of the Poestenkill to the summit of the mountains, including the buildings and real estate appertaining, and including in this more than one hundred acres of land over and above the acreage in the storage ponds in the country, is less than $290,000.

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NEW ENGLAND WATER WORKS ASSOCIATION
MEMBERSHIP ROLL.

SEPTEMBER 1, 1898.

NOTE.—The Secretary requests to be advised of existing errors or change of address from that which appears in the following list.

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Allen, Charles A.
Civil Engineer, 44 Front Street, Rooms 109 and 110, Worcester, Mass.

Allen, Charles F.
Treasurer, Hyde Park, Mass.

Allis, Solon M.
Superintendent, West Troy, N. Y.

Amerman, Lemuel.
Manager Water Works, Coal Exchange, Scranton, Pa.

Andrews, Frank A.
Assistant Superintendent, Nashua, N. H.

Appleton, Francis E.
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Babcock, Stephen E.
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Brooks, E. C.
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Burnie, James.
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Chandler, Henry.
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Chapin, G. L.
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Chapman, Benjamin R.
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Secretary Spring Water Co., Kane, Pa.

Clark, D. W.
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Clark, Frederick W.
Clerk Chestnut Hill Reservoir, Boston Water Works, Brighton, Mass.

Clark, Harry W.
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Colson, Charles D.
Water Commissioner, Holyoke, Mass.

Conant, H. W.
Superintendent, Gardner, Mass.

Conant, Whitney.
Secretary Water Co., Long Branch, N. J.

Connell, Michael A.
Superintendent, St. Hyacinthe, P. Q.

Cook, Byron I.
Superintendent, Woonsocket, R. I.

Cook, Henry A.
Superintendent, Salem, Mass.

Cram, Arthur N.
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Crandall, F. H.
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"Engines," 236 Congress Street, Boston, Mass.

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"Pohlé Air Lift Pump," "Ingersoll-Sergeant Drill Company, 201 Congress Street, Boston, Mass.

Helmer, W. K.

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Hersey Manufacturing Co.

"Meters," South Boston, Mass.

Holly Manufacturing Co.

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"Lead and Tin Lined Pipe," Wakefield, Mass

Ludlow Valve Mfg. Co.

"Valves and Hydrants," Troy, N. Y.

Lynch, John E.

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McNeal Pipe and Foundry Co., The

"Cast Iron Pipe," Burlington, N. J.

Michigan Brass and Iron Works.

"Valves, Hydrants, and Brass Goods," Detroit, Mich.

Moore, Charles A.

"Engines, Boilers, and Supplies," 111 Liberty Street, New York City.

Morris, I. P. Co.

"Pumping Engines," corner Beach and Ball Streets, Philadelphia, Penn.

Mueller, H. Mfg. Co.

"Water Works Supplies," Decatur, Ill.

National Lead Co. (Boston Branch).

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National Tube Works Co.
"Pipe and Fittings," McKeesport, Penn. Address P. W. French, Secretary, 70 Federal Street, Boston, Mass.

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New York Filter Co.
"Filters," 145 Broadway, New York City.

Norwood Engineering Co.
"Hydrants etc.," Florence, Mass.

Peck Bros. & Co.
"Water Works Supplies," 65 Oliver Street, Boston, Mass.

Perrin, Seamans & Co.
"Construction Tools and Supplies," 57 Oliver Street, Boston, Mass.

Pittsburg Meter Co.
"Water Meters," Pittsburg, Penn.

Rensselaer Mfg. Co.
"Valves and Water Gates," Troy, N. Y.

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Hartford Steam Boiler Inspection and Insurance Company, 125 Milk Street, Telephone Building, Boston, Mass.

Robertson, R. A.
Treasurer Builders' Iron Foundry, P. O. Box 218, Providence, R. I.

Ross Valve Co.
"Valves," Troy, N. Y.

Sampson, George H.
"Powder," 147 Pearl Street, Boston, Mass.

Smith, A. P. Mfg. Co.
"Tapping Machines," 921 Prudential Building, Newark, N. J.

Smith, Benjamin C.
"Water Works Supplies," 275 Pearl Street, New York City.

Smith, B. F. & Bro.
"Artesian and Driven Wells," 38 Oliver Street, Boston, Mass.

Snow, Franklin A.
Civil Engineer and Contractor, 490 Broad Street, Providence, R. I.

Snow Steam Pump Co., The.
"Steam Pumps," Buffalo, N. Y.

Star Pipe Jointer Co.
"Pipe Jointers," Quincy, Mass.

Sumner & Goodwin Co.
"Water Works Supplies," 21 Oliver Street, Boston, Mass.

Temby, H. B.
Agent Repauno Chemical Company, 13 Broad Street, Boston, Mass.

Thomson Meter Co.
"Water Meters," 83 Washington Street, Brooklyn, N. Y.

Union Water Meter Co.
"Water Meters," 31 Hermon Street, Worcester, Mass.

Waldo Bros.
"Contractor's Supplies," 102 Milk Street, Boston, Mass.

Walworth Mfg. Co.
"Pipe, Brass Work, Service Boxes, etc.," 16 Oliver Street, Boston, Mass.

Wolfendale, William.
Agent for Plumbers' Supplies, 76 Second Street, Fall River, Mass.

Wood, R. D. & Co.
"Cast Iron Pipe," 400 Chestnut Street, Philadelphia, Penn.

Woodman Co., The George.
"Pipe and Fittings," 41 Pearl Street, Boston, Mass. P. O. Box 3653.

Worthington, H. R.
"Pumping Engines," Hydraulic Works, South Brooklyn, N. Y.

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IMPROVEMENT IN PUMPING ENGINES.

BY. F. F. FORBES, SUPERINTENDENT, BROOKLINE, MASS.

[*Read Dec. 21, 1898.*]

Where real progress has been made in any direction, it is very interesting, and a cause for much satisfaction, to look back and review the struggles which have at last been successful, and also to fully realize that the hours and years of toil have not been in vain. Of the many parts which make up a water works system no one is more important than the pumping engine. In the first place the machine must be reliable, and it also should be accessible in all its parts, so that repairs can be quickly and easily made.

Economy in coal consumption is also a very important feature, as the demand for fuel is a continuous one, and during the last 20 years great gains have been made in reducing the amount of fuel required to pump a certain amount of water. As this economy has been accomplished mostly by the use of machines carrying the expansion of steam over a much greater range, I wish to trace in the briefest manner possible the progress made in this direction.

Twenty years ago the contract requirements for pumping engines were from 50,000,000 to 75,000,000 foot pounds for each 100 pounds of coal burned. Today, as by the specifications for the Chestnut Hill engine, the contract requires a duty of 150,000,000 foot pounds for each 1,000 pounds of dry steam. It is with some amusement that we now look back only a few years to those duty trials conducted with so much care and gravity, and think how much satisfaction the announcement of a duty of 60,000,000 or 70,000,000 gave to all those interested, and how the account of these trials appeared in the technical papers as great achievements

in pumping engines. Changes have rapidly taken place since those times, and we will hastily glance at some of them.

In 1882, sixteen years ago, the first Gaskell high duty crank and fly wheel engine was installed at Saratoga Springs, N. Y., and gave a duty of 112,899,980 foot pounds for each 100 pounds coal burned at the official test. Henry R. Worthington built his first high duty engine in 1885, which was sold to the city of New Bedford, Mass. This engine gave a duty on a 12-hour test of 79,238,160 foot pounds for each 100 pounds of coal burned. Now we come to a new departure in pumping machinery, the introduction of the triple expansion pumping engine. The credit for this new departure belongs to the Edw. P. Allis Co., of Milwaukee, Wis., and the first engine was made in 1886, only twelve years ago, for the city of Milwaukee. This engine had a capacity of 6,000,000 gallons. In 1888 the Holly M'f'g. Co. produced their first triple expansion engine. This engine was sold to Fort Wayne, Ind. In 1889 Henry R. Worthington installed his first triple expansion engine—one of 3,000,000 gallons capacity at Port Perry, Pa.

The Geo. F. Blake M'f'g. Co. made their first engine of this kind in 1890, one of 5,000,000 gallons capacity, and since that date all the other large builders of pumping engines have made more or less triple expansion engines. It may be interesting to note the aggregate daily capacity of triple expansion pumping engines in the United States for each year since they were made to 1898, and also the total daily capacity to the same date.

Table Showing Growth in the use of Triple Expansion Pumping Engines in the United States.

Year.	Capacity of Triple Expansion Engines Made During the Year in Gallons.
1886	6,000,000
1888	123,500,000
1889	29,000,000
1890	29,000,000
1891	37,000,000
1892	96,250,000
1893	97,000,000
1894	60,500,000
1895	116,000,000
1896	187,375,000
1897	435,750,000

Total daily capacity.......1,217,375,000 gallons.

These figures give us an idea of the marvelous growth in the use of engines of this class—a growth made imperative by the great saving they produce. Now what economical results may we confidently expect of the engine of today? We can safely answer that a triple expansion engine can be obtained at a moderate price, which will give a duty of 140,000,000 to 160,000,000 foot pounds for each 1,000 pounds steam used. Now think what this means. It means that today we can pump the same amount of water with $\frac{1}{2}$ to $\frac{1}{3}$ of the coal required 20 years ago, and although the money value of the coal saved in this way may be greater than the net saving owing to the larger capital invested, and the additional help which may be required in some cases, yet when the amount of water pumped per day is not larger even than 1,000,000 gallons, unless the head be very low, a high duty engine will be found much cheaper in the end.

An account of work done is always more convincing than theory, and in closing this brief history the following table is appended to show what the town of Brookline has saved in fuel by the use of a triple expansion, crank and fly wheel engine. This table includes all the coal used at this station for all purposes with no deduction for ashes or moisture. You will notice that with an engine of a capacity of 5,000,000 gallons per day, the average amount pumped was little more than $\frac{1}{4}$ of this quantity. Had the engine been in use more hours each day the economic results would have been much greater.

Record of Work Done at the Low Service Pumping Station of Brookline, Mass.

Year.	Gallons Pumped.	Coal consumed in pounds for all purposes. No deductions.	Gallons per pound of coal.	
1890 ..	322,767,796	1,141,175	282.8	
1891...	356,812.572	1,263,395	282.4	
1892 ...	390,593,090	1,351,032	289.1	
1893 ..	443,973,099	1,582,471	280 5	
1894....	481,633,366	998,107	482.5	Triple expansion engine, in use part of the time.
1895 ...	483,969,131	803,642	602.2	In use most of the time.
1896....	494,095,562	745,692	662.6	In use all the time.
1897 ...	508,174,048	761,826	670.0	In use all the time.

Average number of gallons pumped per day in 1897....... 1,392,258
Coal required if old engine had performed this work....... 1,791,238 lbs.
Coal actually consumed .... 761,826 lbs.
Coal saved.. 1,029,412 lbs.

In January, 1896, two coal tests were made of the triple expansion vertical crank and fly wheel engine at Brookline. Mass., to determine the relative duty at different speeds.

It has been stated that a crank and fly wheel engine when run at a speed much slower than the contract requirements, shows a greater loss in economy than a direct acting duplex engine working under the same conditions. The test at Brookline, however, shows that with the conditions which existed at that station the performance of the engine in relation to economy in steam consumption was practically the same at the different rates of speed under which the engine was tested. The lower duty on a coal basis at the slower speed is explained in two ways: First, the coal burned per square foot of grate surface per hour in the second test was too small to give best results, and the water evaporated per pound of coal was $6\frac{2}{10}$ per cent. less. Second, the radiation of the boiler steam pipes and engine is nearly the same per hour at all rates of speed of the engine, and consequently the loss due to radiation forms a greater per cent of the work done as the work performed by the engine decreases.

Making corrections due to power, evaporation and increased loss of radiation, the duty of the engine was slightly better at the slower speed, being 140.3 million foot-pounds, and the actual duty of the faster speed being 140.1 million foot-pounds.

The test was a long one, lasting over twenty-eight hours, each, in order to make the error as small as possible due to more or less coal on the grates at the close of the test, water in the boiler, etc. Before the test all the gauges, and the scales for weighing the coal were tested and made correct. The data of the tests were all carefully taken at intervals of fifteen minutes. The results are appended, and I think will be of interest:

TEST NO. 1.

1. Duration of test—28 hours 26 minutes.
2. Total revolutions—50,276.
3. Revolutions per minute—29.5.
4. Total gallons pumped—5,982,844.
5. Total head against plungers—202.18 feet.
6. Total wet coal—7,200 pounds.
7. Coal per hour—253.3 pounds.
8. Moisture in coal—2.77 per cent.
9. Refuse in coal—6.63 per cent.

10. Total non-combustible—9.4 per cent.
11. Grate surface—25.0 square feet.
12. Coal per hour square foot of grate—10.13 pounds.
13. Duty per 100 pounds of wet coal—140,113,320 foot-pounds.

Jacket Water, Etc.

14. Drain from high and intermediate cylinder jackets ; first and second receiver jackets, and drain from separator on main steam pipe—8,708 pounds (returned by gravity to boiler).
15. Temperature of jacket returns near boiler—320° F.
16. Drain from low pressure cylinder jacket—2,032 pounds (drained into feed tank).
17. Drain from high pressure steam chest and bottom of high pressure cylinder—73 pounds 1 ounce per hour (drained into sewer through coil in feed tank).
18. Temperature of water pumped, main engine—50° F.
19. Temperature of water in feed tank—125° F.
20. Temperature of air pump discharge—108° F.
21. Temperature of gases in boiler uptake—418° to 511° F.
22. Steam pressure by gauge at engine—130 pounds.
23. First receiver—21.5 pounds.
24. Second receiver—minus 3.4 pounds.
25. Vacuum—13.2 pounds.
26. Coal used—George's Creek, Jackson Mine.

Manner of Firing.

Coal spread on front of grate every 7½ minutes. Fire leveled off, furnace doors closed, and automatic damper allowed to nearly close one minute before each firing. Hand damper nearly closed before opening furnace doors. Coal sprinkled with warm water before using. Condition of fire, height of water in boiler, and steam pressure the same at beginning and end of test.

TEST NO. 2.

1. Duration of test—28 hours 45 minutes.
2. Total revolutions—37,089.
3. Revolutions per minute—21.5.
4. Total gallons pumped—4,413,591.
5. Total head against plungers—183.05 feet.
6. Total wet coal consumed—5,100 pounds.
7. Coal per hour—177.4 pounds.
8. Moisture in coal—2.77 per cent.
9. Refuse in coal—6.85 per cent.
10. Total non-combustible—9.62 per cent.
11. Grate surface—25 square feet.
12. Coal per hour per square foot of grate—7.1 pounds.
13. Gallons pumped per pound of wet coal—865.4 gallons.
14. Duty per 100 pounds wet coal—132,116,693 foot-pounds.

JACKET WATER, ETC.

15. Drain from high and intermediate cylinder jackets ; first and second receiver jackets, and drain from separator on main steam pipe—6,840 pounds (returned by gravity to boiler).

16. Drain from separator only—672 pounds.

17. Drain from low pressure cylinder jacket—1,713 pounds.

18. Water returned from jackets and separator—6,840 pounds.

19. Total feed water—50,965 pounds.

20. Steam condensed in jackets—7,881 pounds. (15.464 per cent).

21. Temperature of water pumped—50°.

22. Temperature of water in feed tank—114°.

23. Temperature of discharge from air pump—98°.

24. Steam pressure (by gauge) at engine—130 pounds.

25. First receiver—16.5 pounds,

26. Second receiver—minus 3.5 pounds.

27. Vaccuum—13.6 pounds.

28. Coal used--George's Creek, Jackson Mine.

THE POSSIBILITIES OF ECONOMY IN PUMPING ENGINES AS BASED ON THE LATEST ACCOMPLISHMENTS.

BY GEO. H. BARRUS, M. E., BOSTON, MASS.

[*Read Dec. 14, 1898.*]

The highest interest in the possibilities of the performance of pumping engines has been awakened by the results obtained from a 20,000,000 gallon engine built by the Snow Steam Pump Works of Buffalo, N. Y., for the Indianapolis, Water Co. According to a duty trial made by Prof. Goss of Purdue University, this engine gave a duty of 150.1 million foot-pounds, based on a consumption of 1,000,000 heat units, and 167.8 million foot-pounds based on a consumption of 1,000 pounds of dry steam. These results, are, I believe, higher than any heretofore published, and are naturally viewed by engineers and users of pumping engines with deep interest.

In the following table a comparison is made between the essential features in the performance of this engine, with those of a number of other prominent engines which have been carefully tested within the past five years, together with some data and calculations made by the writer not found in the published reports of the tests; and I propose in this paper to present a brief examination of these trials, with a view to showing what it is reasonable to expect of the duty of a pumping engine under the best obtainable conditions.

The data given in this table for the Milwaukee engine are taken from Vol. XV., Transactions of the American Society of Mechanical Engineers; that for the Chestnut Hill engine from Vol. IX., Technology Quarterly; that for the Detroit and Buffalo engines from the original official reports, and that for the Indianapolis engine from a typewritten copy of Prof. Goss' report, furnished by Mr. Davis, president of the Indianapolis Water Co.

1. Name of designer or builder	E. P. Allis Co.	E. D. Leavitt, Jr.	E. P. Allis Co.	Lake Erie, Eng. Works.	Snow Steam Pump Works.
2. Locality	Milwaukee, Wis.	Chestnut Hill, Mass.	Detroit, Mich.	Buffalo, N. Y.	Indianapolis, Ind.
3. Type	Trip. Ex.	Trip. Ex.	Trip. Ex.	Trip. Ex.	Trip. Ex.
4. Extent of jacketing	Barrels and receivers.	Barrels, heads and receivers.	Barrels and receivers.	Barrels and receivers.	Barrels, heads and receivers.
5. Name of expert conducting test	Prof. R. C. Carpenter.	Prof. E. F. Miller.	Geo. H. Barrus.	Geo. H. Barrus and Newcomb Carlton.	Prof. W. F. M. Goss.
6. Capacity—million gals. in 24 hours	18.	20.	24.	30.	20.
7. Size of steam cylinders, in.	28, 48, 74 x 60	13.7, 24.37, 39 x 72	28, 48, 74 x 60	37, 63, 94 x 60	29, 52, 80 x 60
8. Size of water plungers, in.	32 x 60	Double acting. 17.5 x 48	36 x 60	42 x 60	33 x 60
9. Total head, lbs.	70.4	59.4	53 4	86.1	88.7
10. Piston speed feet per minute	203.1	607.	209.9	207.7	214.6
11. Ratio of volume of L. P. cylinder to volume of H. P. cylinder	7.1	8.3	7.1	6.5	7.7
12. Pressure near throttle(above atmosphere) lbs	121.4	175.7	125.2	167.1	155.6

13. Cut-off pressure (above atmosphere), lbs.	118.6	151.5	119.4	152.2	153.
14. Release pressure, L. P. cylinder (above zero), lbs.	5.3	6.9	5.8	7.4	6.4
15. Back pressure L. P. cylinder (above zero), lbs.	1.6	1.5	2.8	2.2	. 2.5
16. Cut-off, H. P. cylinder	.337	.384	.338	.323	.315
17. Clearance, H. P. cylinder . . .	.014	.015	.014	.014	.018
18. Ratio of expansion	20.4	21.	20.3	19.6	23.8
19. Ratio of expansion referred to pressure near throttle	20.8	23.9	21.2	21.3	24.3
20. Absolute pressure near throttle ÷ ratio of expansion, lbs. . . .	6.6	9.1	6.9	9.3	6.8
21. Indicated horse power, I. H. P. .	573.9	575.7	573.7	1185.5	775.5
22. Friction, %	9.2	10.5	10.2	5.1	4.6
23. Dry steam per I. H. P. per hour, including jacket and reheater steam, lbs.	11.68	11.22	12.52	12.39	11.26
24. Per cent of steam condensed in jackets and reheaters, % . . .	9.2	17.1	12.7	13.7	10.5 (est.)
25. Dry steam per I. H. P. per hour, exclusive of steam used in jackets and reheaters, lbs.	10.61	9.3	10.93	10.7	10.08 (est.)

26. Steam accounted for by indicator, H. P. cylinder cut-off, lbs. . .	9.05*	8.5*	9.5	9.1	8.7*
27. Steam accounted for by indicator, L. P. cylinder cut-off, lbs. . .	8.7*	9.6*	9.5	9.7	8.7*
28. Steam accounted for by indicator, L. P. cylinder release, lbs. . .	9.04*	9.1*	9.9	9.7	9.8*
29. Cylinder condensation and leakage, including jacket and reheater condensation, at cut-off, H. P. cylinder	.225	.242	.241	.266	.227
30. Mean effective pressure referred to L. P. cylinder, lbs.	21.77	26.36	21.03	27.19	23.65
31. Theoretical mean effective pressure referred to pressure near throttle valve and ratio of expansion at same point	26.42	33.23	26.76	34.63	29.66
32. Line 30 ÷ line 31, or "diagram factor"	.824	.794	.792	.786	.797
33. Duty based on 1,000,000 heat units, expressed in million foot-pounds	137.	141.9	129.7	135.4	150.1
34. Duty based on 1,000 lbs. of dry steam, expressed in million foot-pounds	154.0	154.9	142.4	152.	167.8

*Calculated by G. H. B.

I have carefully examined the reports and records of these tests, and I believe them all to be substantially reliable. In the report of the Indianapolis test, Prof. Goss states that the indicator diagrams, owing to long driving cords, are not altogether satisfactory. The diagrams are, on this account, of different lengths, it is possible that the indicated horse-power is greater than the amount reported and the friction greater by a corresponding amount; but it should be observed that whatever increase there may be in this direction, makes the steam consumption per indicated horse-power per hour correspondingly less. As this, as it stands, is an exceptionally low quality, the error, if any, must be a small one. I understand that this test has just been repeated, and Prof. Goss reports that the results obtained on the first test have been completely verified.

With the exception of the two tests conducted by the writer, there is no published statement as to the condition of the valves and pistons of the steam cylinders as regards tightness, and the precise conditions in this respect must be inferred from the character of the results. As to the Detroit and Buffalo engines, the valves and pistons were tested for leakage with the engines at rest, subjected to the working pressures; and in neither case was the engine found to be in the best condition. Both of these engines leaked to some extent.

The economy with which an engine uses steam, assuming a proper ratio of expansion, is dependent upon three things: First, the steam pressure; second, the efficiency with which the theoretical expansive force of the steam is realized, as shown by the proportion which the area of the actual indicator diagram bears to the theoretical diagram; and third, the quantity of cylinder condensation and leakage. An increase in the steam pressure, an increase in the proportion of the theoretical expansive force realized in the actual diagram, and a decrease in the quantity of cylinder condensation and leakage, all tend toward greater economy of the engine; that is, to a reduction in the quantity of steam used in producing a given amount of power. As applied to pumping engines in which the economy is measured by the amount of water pumped by a given unit of energy (such as the energy produced by the combustion of 100 pounds of coal, or the consumption of 1,000 pounds of steam, or by the use of 1,000,000 heat units), the economy is

dependent, also, upon the efficiency of the mechanism of the engine and pump, that is, upon the friction; the smaller the friction, the greater the amount of useful work done by the given unit of energy. That a proper comparison may be made of the results of the tests of these five engines, the data and calculations showing these four controlling factors are here presented. Line 12 gives the pressure; line 32, the diagram factor, or the proportion which the actual mean effective pressure measured from the diagrams bears to the theoretical mean effective pressure; line 29, the cylinder condensation and leakage at cut-off H. P. cylinder (including condensation in jackets and reheaters); and line 22, the friction, this applying to the entire mechanism and the friction of the water between the pump well and the discharge main.

In the Milwaukee engine the pressure is 121.4 pounds, which is low compared with most of the other engines; the diagram factor is .824, which is the highest of all; the cylinder condensation and leakage at cut-off H. P. cylinder is .225, which is the lowest of the whole list; the friction is 9.2 per cent., which is comparatively high; and the duty based on heat units is 137,000,000.

In the Chestnut Hill engine the pressure is the highest of all the engines given in the table, being 175.7 pounds. The diagram factor, however, is with one exception the lowest given in the table, being .794. The cylinder condensation and leakage at cut-off H. P. cylinder is .242, and the friction, 10.5 per cent., both of which are comparatively high. The duty in this case is 141.9 millions on the heat unit basis.

In the Detroit engine the pressure is 125.2 pounds; the diagram factor is .792, which is the lowest of all; the cylinder condensation and leakage at cut-off H. P. cylinder is .241, and the friction is 10.2 per cent.; all of which are medium results compared with their fellows.

In the Buffalo engine the pressure is 167.1 pounds, which is nearly the highest of the whole list; the diagram factor is .786; the cylinder condensation and leakage at cut-off H. P. cylinder is .266, which is larger than any other figure of the whole five engines; and the friction is 5.1 per cent., one of the lowest. The resulting duty, based on heat units, is 135.4 millions.

In the Snow engine the pressure is 155.6 pounds, which is a medium figure compared with the others; the diagram factor is

.797; the cylinder condensation and leakage at cut-off H. P. cylinder is .227, which with one exception is the lowest of all; and the friction is 4.6 per cent., which is smaller than any other on the list. With substantially one exception, all these quantities are the most favorable to high economy of any in the table.

In the light of what this analysis reveals, a duty of 150,000,000 foot-pounds of work for 1,000,000 heat units is a result which ought to be readily duplicated, and very likely surpassed, by any of the various types of engines here referred to, provided they are given an equally favorable opportunity. Let us go over the list and see what the possibilities are in the case of the engines which gave the lower duties, provided the conditions referred to were more favorable. The Milwaukee engine worked under a steam pressure of 34.2 pounds below that of the Indianapolis engine. I estimate that if the pressure had been raised in the Milwaukee engine to the same point, with a corresponding increase in the ratio of expansion, the duty would have been increased 7.1 per cent. Furthermore, if the friction of the Milwaukee engine had been no greater than that of the Indianapolis engine, the duty would have been still further increased 5.1 per cent. These two changes would have brought the duty per 1,000,000 heat units, up to 154.2 million foot-pounds. Again, if the Chestnut Hill engine had operated with the same cylinder condensation and leakage as the Indianapolis engine, the duty would have been increased 2 per cent.; and, further, if the friction had been no greater in one case than in the other, the duty would have been increased 6.6 per cent. more, bringing the final result up to 154.2 millions. In the Detroit engine an increase in the boiler pressure from 125.2 pounds up to 155.6 pounds, with a corresponding increase in the ratio of expansion, would have increased the duty, according to my estimates, to the extent of 8.2 per cent. If the cylinder condensation and leakage had been no greater in one case than in the other, the duty would have been further increased 1.9 per cent. If, also, the friction had been only 4.6 per cent., there would have been a still further increase in the duty of 6.5 per cent., making the final result 152.3 millions.

The possibilities of economy in pumping engines, as based on the latest accomplishments, in a word, seem to be that with a boiler pressure of 175 pounds per square inch, a diagram factor, cylinder condensation and leakage as favorable as obtained in the Milwaukee

engine, and the friction as low as 5 per cent., which appears to be capable of realization, a duty can be obtained of at least 155,-000,000, and possibly 160,000,000 foot pounds, for the expenditure of 1,000,000 heat units.

DISCUSSION.

THE PRESIDENT. The paper is now open for discussion, and we would like to hear from anyone present, particularly from the mechanical engineers, quite a number of whom are here. I will call upon Mr. F. W. Dean.

MR. DEAN. Mr. President, some years ago at the Worcester meeting I read a paper before this Association on Pumping Engines, and I thought to-day I would come to listen and not to talk. Of course these records of performances are very interesting, and I think we all ought to be grateful to Mr. Barrus for collecting the records in this shape, which is convenient to file away.

The question of the possible duty of a pumping engine is something which is occurring to people all the time, and I think we have the right to expect that even this high duty of the Snow engine will be exceeded in a few years. It is within the range of possibility that steam consumption may come down another quarter of a pound, and I do not know but there may be people who will be willing to guarantee that it will. I have been told that the Edward P. Allis Company would guarantee 11 pounds of steam; I don't know whether that is so or not, but I hope we will find out from Mr. Reynolds. Of course when you get down to small results quarter pounds count, and they are equally difficult to drop off from the result. I received quite recently a catalogue of engines from the Wheelock Engine Co., of Worcester, in which they state on the fly-leaf that they are prepared to guarantee a consumption of one pound of coal per indicated horse power per hour. Now, I do not deny that the consumption can be brought down to that point, for it is barely possible, in fact I know it is possible, to get an actual evaporation from a pound of coal of something over 11 pounds. I did that with two tests on a New Bedford water works boiler myself, just a shade over 11, and with the feed-water of 130 degrees, I believe. Now, if the feed-water by some means or other could have been brought up to 200 degrees, there would be 70 degrees more, which would mean about 7 per

cent. of coal saved, and the resulting boiler performance connected with one of these highly economical engines, I have no doubt would have brought the coal consumption down to one pound. So, while it is a very hazardous thing to make any such guarantee as that, it is not an impossibility. Anybody who has had experience in obtaining guarantees in boiler performances, knows how hazardous it is to meet the guarantee with them. While one can quite safely guarantee the perfoamance of an engine, if he is careful to see everything in it is tight, when you come to a boiler, no matter how good the boiler is, you always have present the means of the poorest possible performance in the world, even if the boiler is the best one in the world. I have myself quite recently had a terrific struggle to get one of the best boilers in the world to give anything better than the poorest result. It was finally done, however, by finding a man who happened to have the right kind of brains to enable him to put in his coal properly and watch his fire properly.

PRESENT PUMPING ENGINE PRACTICE OF THE EDWARD P. ALLIS CO. COMPARED WITH THAT OF TWENTY-FIVE YEARS AGO.

BY IRVING H. REYNOLDS.

[*Read Dec. 14, 1898.*]

The great advance in the economy of pumping engines during the past twenty-five years, and the decrease in cost of high duty engines during this period, may perhaps render of interest to you an engineer's review of the causes which have brought about this dual result.

Twenty-five years ago, 75,000,000 duty was a high guarantee, and 100,000,000 the maximum that had been obtained, while today 150,000,000 duty is guaranteed, and 160,000,000 duty appears within reach if not already attained. The cost of high duty engines twenty-five years ago was for ordinary heads approximately $10,000 per million gallons capacity while today machines 50 per cent. more economical can be purchased for one-third of this price.

The work of the Edward P. Allis Company illustrates very well the increase in economy and decrease in cost of pumping engines during the past quarter of a century, but before going into details of this I wish to mention some of the pioneer work of others.

The compound engine, which has been the greatest factor in increasing the economy, appeared as a pumping engine early in the seventies, and I believe Mr. Leavitt's Lynn engine was the first machine to give 100,000,000 duty on coal, the Lowell engine, designed by Mr. Morris, built just previously giving a duty of 94,000,000.

The introduction of the compound engine was opposed by many, as was the introduction of the triple twenty years later, and so prominent an engineer as Geo. H. Corliss, whose name is identified with the progress of steam engineering, was bitterly opposed to the compound engine, and constructed the remarkable Hope street engine at Providence about 1873, making it a simple condensing

machine. The result was that at one-half speed (contract conditions) it gave a duty of only about 25,000,000 foot-pounds, while a compound Worthington machine, tested at the same time, gave a duty under similar conditions of over 50,000,000.

After the failure (as to economy) of the Hope street engine, Mr. Corliss built another simple condensing engine (which still stands in the Corliss works), which was to finally demonstrate that there was nothing to be gained by compounding. This was a comparatively high speed Corliss engine geared to a ten plunger pump, and with this he succeeded in getting a duty of about 60,000,000. After this he built an experimental compound pumping engine which was operated in his shops, and many years later was sold to Easton, Pa., and in 1877 he sold his first compound pumping engine, the now justly celebrated Pawtucket machine, which held the compound duty record for many years.

It is interesting to note that the tests of Mr. Corliss' experimental engines were conducted by the now well known yacht builder, Mr. N. G. Herreshoff, and the valve gear and some other details of the Pawtucket engine were designed by him.

The above is sufficient to show that there existed a difference of opinion as to the merits of compound engines.

The Allis Company built their first pumping engine in 1873, it being a double machine of 16,000,000 gallons capacity. The engine, which was designed by Mr. R. W. Hamilton, was one of the over-head beam type, and similar in general style to engines in the Brooklyn Water Works, and also in the London (Eng.) works, excepting that it was compound, while the others were not. This engine cost, with its boilers, about $165,000, or at the rate of over $10,000 for each million gallons capacity, and was guaranteed to develop a duty of 60,000,000 foot-pounds for each hundred pounds of anthracite coal, and on a 48-hour test gave a duty of about 76,000,000.

In 1881 the Allis Company built their second pumping engine, designed by Edwin Reynolds, which was also a compound vertical beam engine having a capacity of 12,000,000 gallons in 24 hours, and costing about $65,000, or at the rate of $5,400 per million gallons capacity. This engine with 80 pounds steam pressure developed a duty of nearly 105,000,000 per 100 pounds of coal.

In 1891 an 18,000,000 gallon triple expansion pumping engine

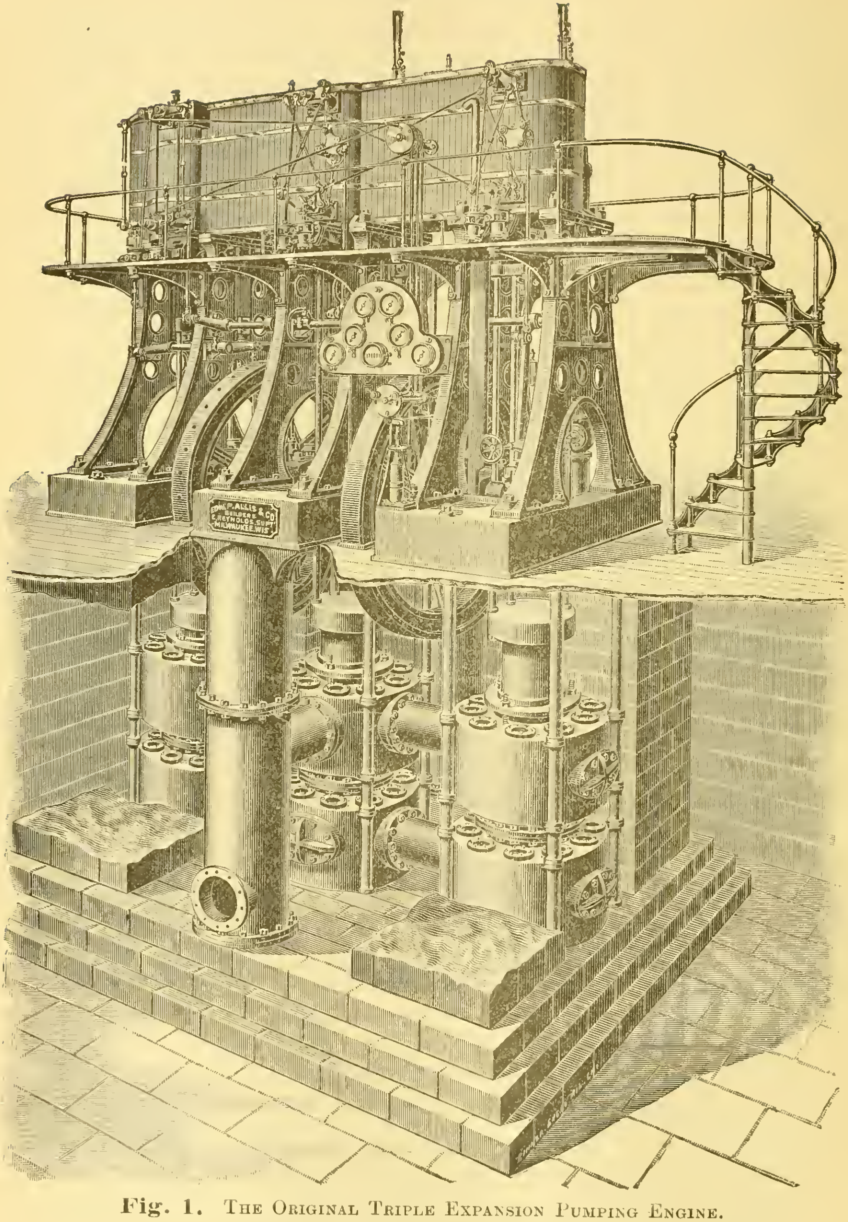


Fig. 1. THE ORIGINAL TRIPLE EXPANSION PUMPING ENGINE.
Built in 1886 by The Edw. P. Allis Co.

(see Fig. 4) was placed in the Milwaukee Water Works, which cost, together with its boilers, $76,000, or at the rate of $4,222 per million gallons capacity, the guaranteed duty being 125,000,000 foot-pounds per 100 pounds of anthracite coal. It will be seen that this engine, though of greater capacity, cost less than one-half the price of the original 16,000,000 gallon engine placed in the same station eighteen years before. The duty guaranteed was double, and in addition the space occupied was only about one-half that required by the earlier machine, and the cost of foundations was considerably less than half. In brief, eighteen years' progress of one builder represented equal capacity with double the duty at one-half the cost. I shall have occasion to speak of the performance of this last engine a little further on.

Between 1881 and 1886 the Allis Company built sixteen compound pumping engines of various types, some of them giving duties as high as 107,000,000 foot-pounds per 1,000 pounds of steam.

Nearly all of the earlier crank and fly-wheel pumping engines were of the beam type, in fact this type of engine was so universal that it almost seemed as though it was considered one of the fundamental requirements, and until 1886 all of the Allis pumping engines with the exception of two engines (Figs. 2 and 3) were of this type, but since the introduction of the triple in 1886 it has been our almost universal practice to build direct connected engines, avoiding entirely all forms of beams, bell cranks, or levers. We have settled down to practically three designs—the vertical triple expansion, the vertical compound, and the horizontal compound types.

A brief mention of the origin and development of the triple expansion engine will not be out of place here.

In 1886 the Allis Company built from the writer's designs, the first triple expansion pumping engine. (Fig. 1). This engine, which was constructed for the high service station in the Milwaukee Water Works, was the first triple expansion pumping engine built in America, and as far as I can learn the first to be designed by anyone, although an engine was constructed at about the same time for the East London (Eng.) Water Works.

It is a rather remarkable coincidence that two designers, totally unacquainted with each other or with the other's work, should at

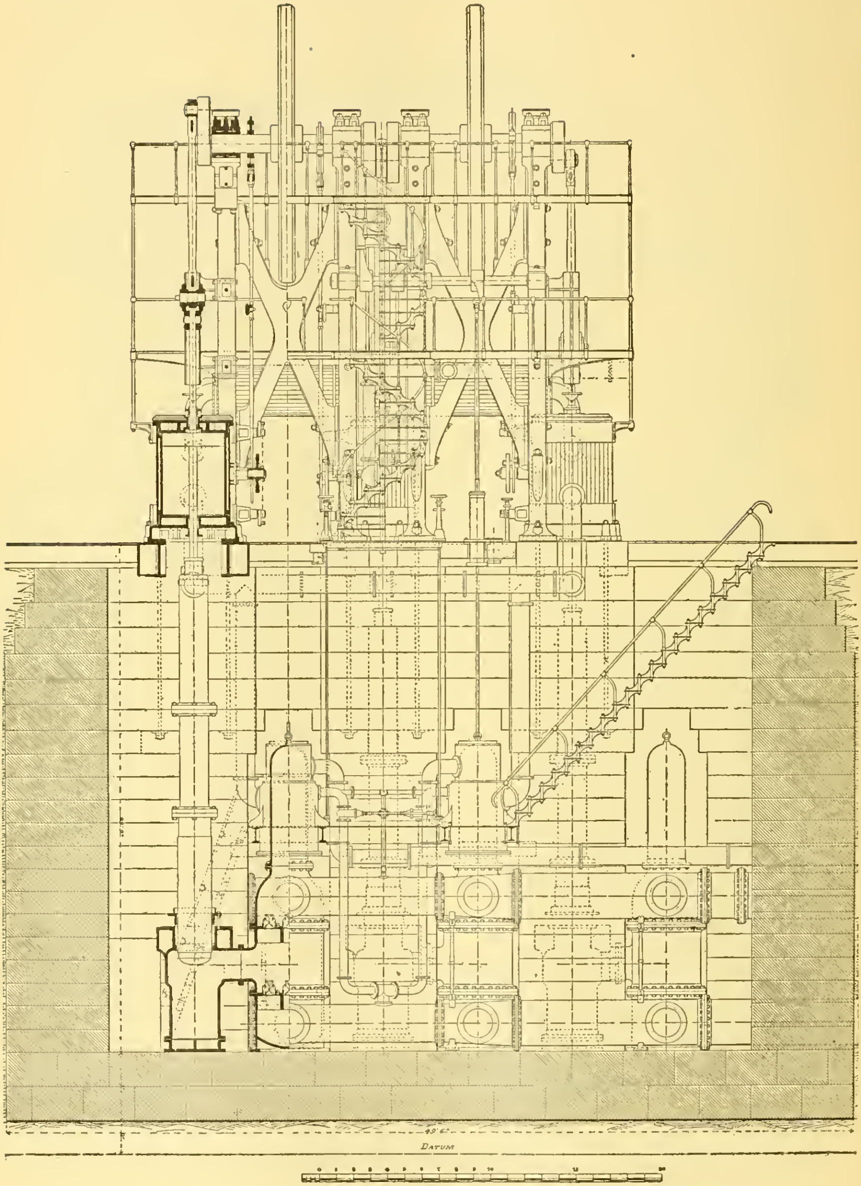


Fig. 2. Side Elevation.
THREE CRANK COMPOUND ENGINES.
Built 1883.

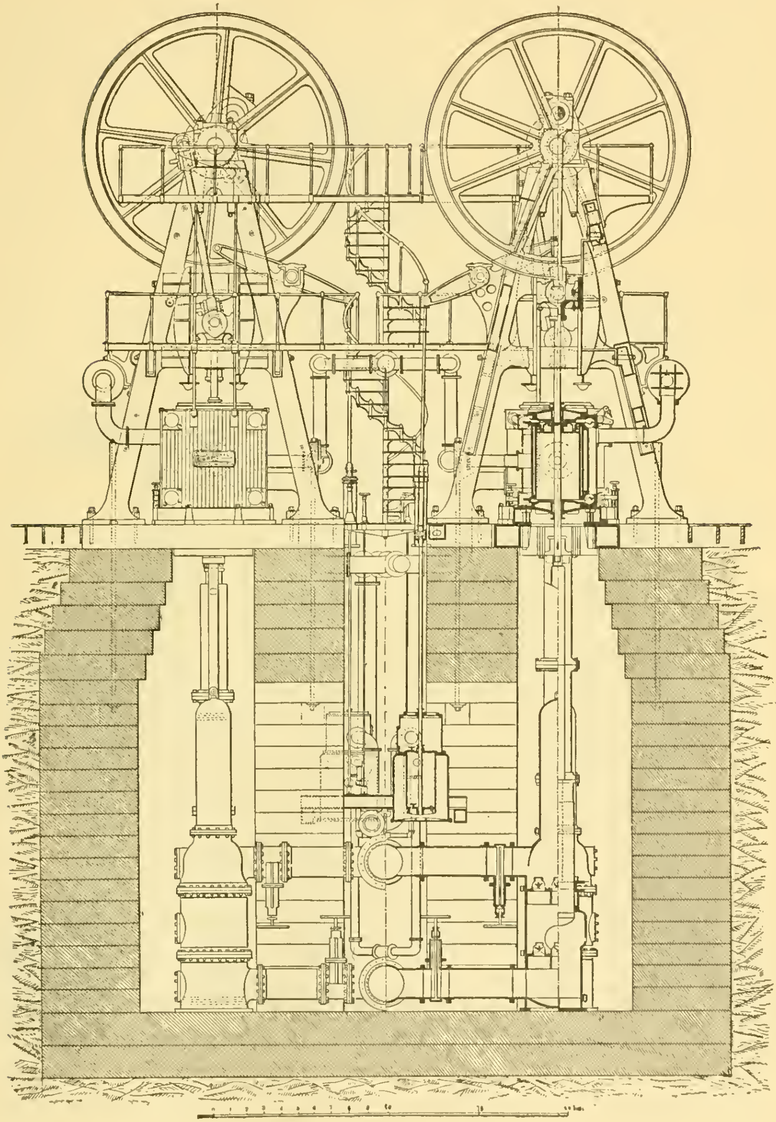


Fig. 3. End Elevation (2 Engs.)
THREE CRANK COMPOUND ENGINES.
Built 1883.

the same time design machines so similar in their general outlines. The English engine, however, was built from Marine engine patterns, fitted with piston and slide valves, and although supplied with steam at nearly double the pressure of the Allis engine, never attained as high economy.

The Milwaukee triple was guaranteed to develop a duty of 118,000,000 foot-pounds for each 100 pounds of anthracite coal burned, the steam pressure being limited by the city's specifications to 80 pounds, the guarantee being unprecedentedly high for such low steam pressure. But the engine actually developed a duty of over 125,000,000 foot-pounds per 100 pounds of coal burned. This engine was a developmont of the three crank compound engines designed by Mr. Edwin Reynolds originally for the Nashville, Tenn. Water Works, but built in 1883 for the Allegheny, Pa. Water Works. (Figs. 2 and 3).

The triple expansion engine was an immediate success, and the original engine has been copied in all of its essential features by nearly all builders of high duty pumping engines, and I believe I may safely say is the standard type of high duty pumping engine today.

The Allis Company has built 45 triple expansion pumping engines, 33 of them being of the vertical and 12 of the horizontal type, and engines of this general type, by the Allis Company and other builders, are in use in all of the important cities of the country. Milwaukee has 3, Chicago 6, Philadelphia 6, New York 4, Boston 5 under construction (besides the Leavitt Chestnut Hill engine, which has been running several years); Buffalo 2, St. Louis 4, (and 5 more in contemplation), while other machines are in New Orleans, Cleveland, Detroit, etc. The above list is not at all complete, but I believe is sufficient to show that the type has been accepted as a standard.

I am an advocate of the triple expansion engine, not solely because of the economy due to the triple expansion steam end, but more particularly because it is a triplex pump, which on account of the arrangement of the three cranks, gives a practically uniform flow of water with pumps of very simple construction. For this reason I consider the triple expansion engines which have say two plungers, and either three or four steam cylinders, but little better than compound engines, for while they undoubtedly effect some

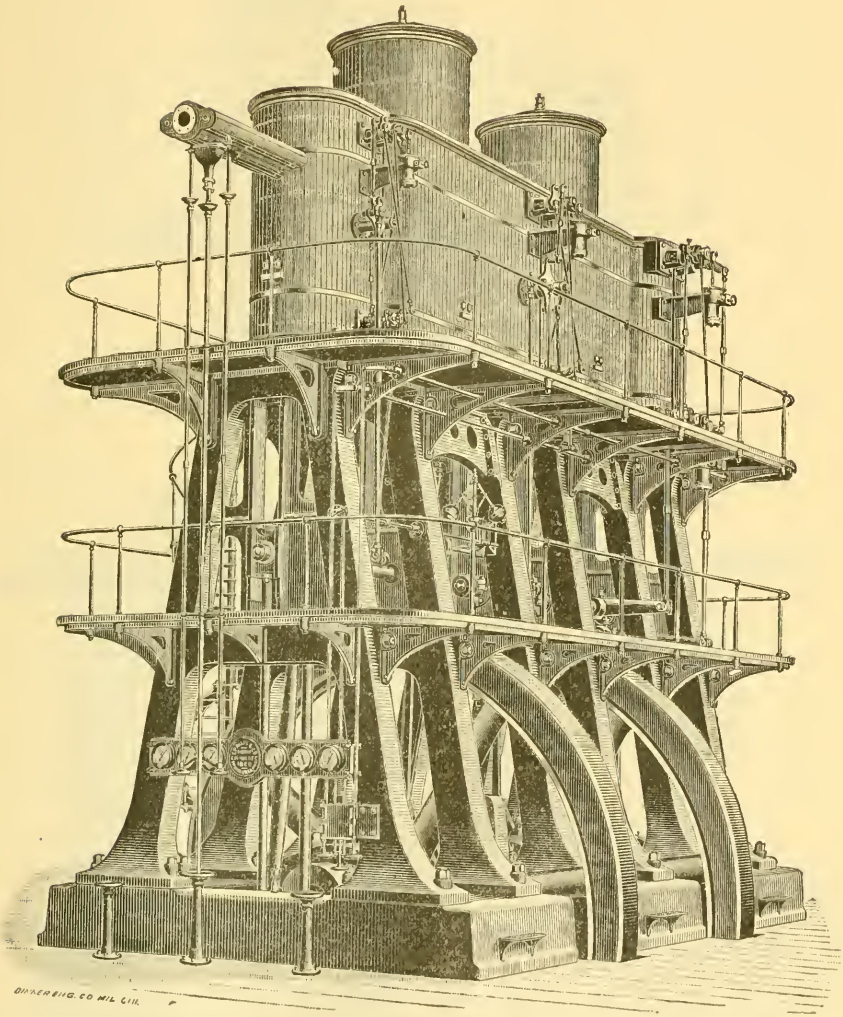


Fig. 4.

Triple Expansion Pumping Engine.

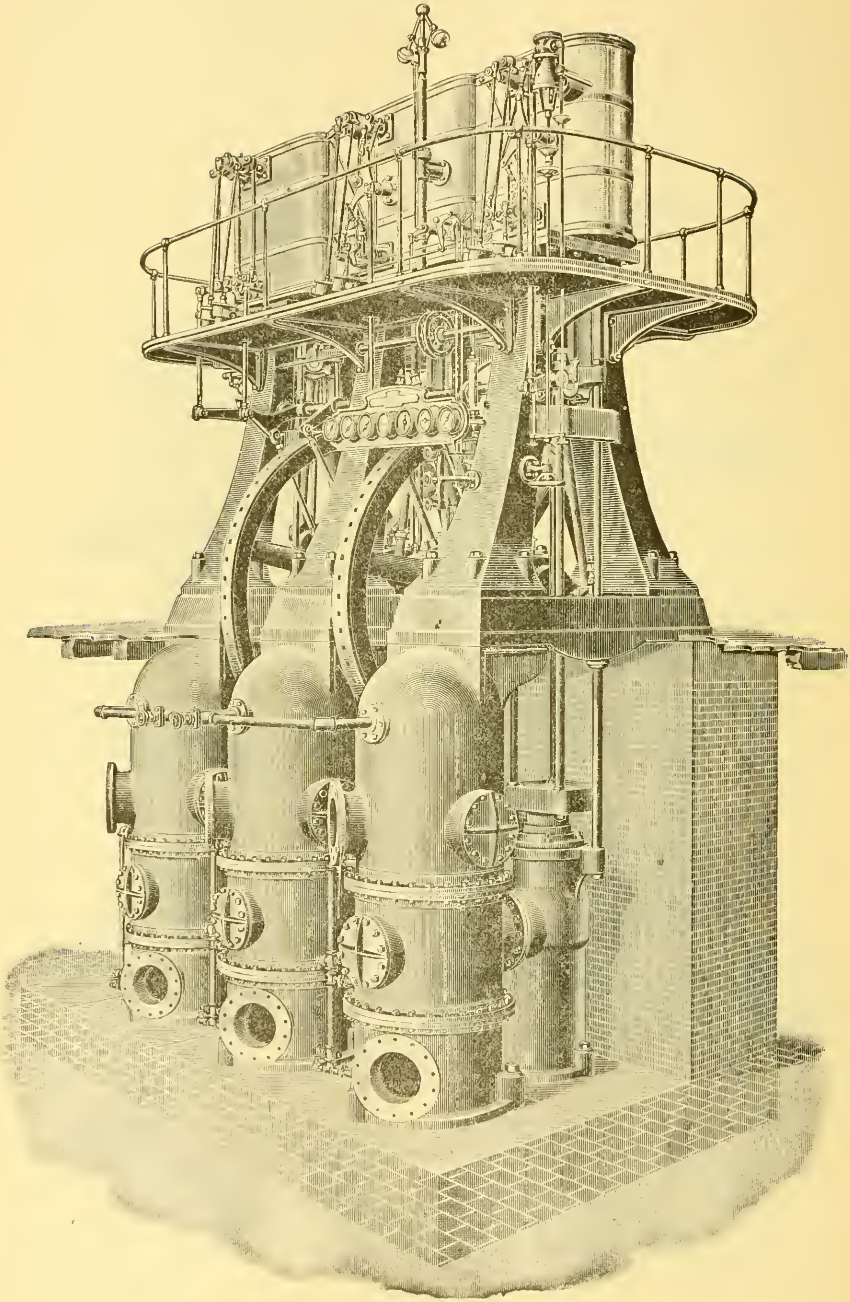


Fig. 5.
The Reynolds Triple Expansion Pumping Engine.

gain in economy, the delivery of water is no better than that of the compound engine.

On this point I cannot agree with Mr. Leavitt as to the relative merits of the single crank and three crank engine, as expressed by him before your Association in 1894, for I believe that the three crank engine, solely because of its merit, has come to stay, and I feel equally sure that the single crank beam engine will become practically obsolete in the near future. This opinion is based not only on pumping engine practice, but on general steam engineering practice the world over, which tends towards simple and direct machines.

In addition to its superior mechanical features, the triple expansion engine will give from 10 to 15 per cent. higher economy than compound engines of the same general construction working under similar conditions, even with steam pressures of 100 pounds or less.

TRIPLE EXPANSION ENGINE.

The triple expansion pumping engines built by the Allis Company are so well known, and the illustrations show them so clearly that the following brief description is hardly necessary:

These engines are of the vertical 3 cylinder type, similar in general outline to the ordinary triple expansion marine engine. The steam cylinders are mounted on top of cast iron "A" frames, each steam piston being attached directly to its own pump plunger by means of piston and distance rods connecting to a cross-head. From this cross-head extends the connecting rod to crank pin. The crank shaft has three cranks set at 120°, the shaft being in two pieces, with the center crank fitted with drag boxes to prevent breaking or straining the shaft in case the engine gets out of alignment. There are two fly-wheels on the shaft to secure a steady turning effect, although with a three crank engine it is possible to run with very light ones, or even without wheels.

Corliss valve gear is fitted to all of the cylinders of the smaller engines, the larger engines having Corliss valves on the high and intermediate cylinders, and poppet valves on the low pressure cylinder.

The steam cylinder barrels are jacketed, and the steam and exhaust valves are placed in the cylinder heads.

The engine is fitted with a fly-ball governor and also hand cut-off

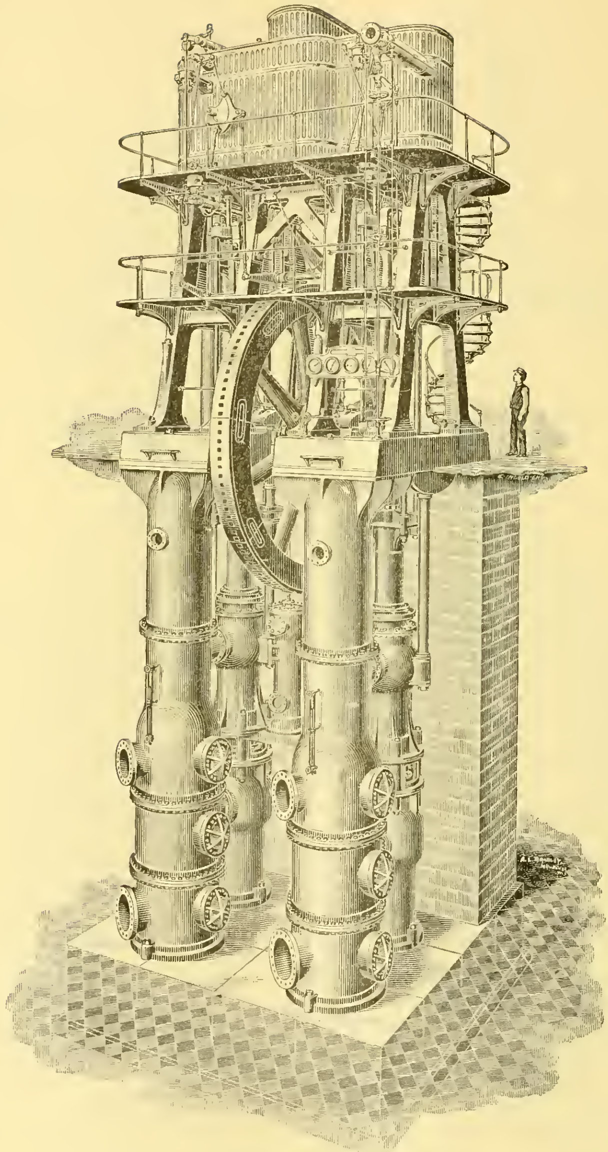


Fig. 6.

Four Vertical Compound Pumping Engines.

Built for Pittsburg, Pa. Cylinders 50″ and 92″ diam. x 64″ stroke.

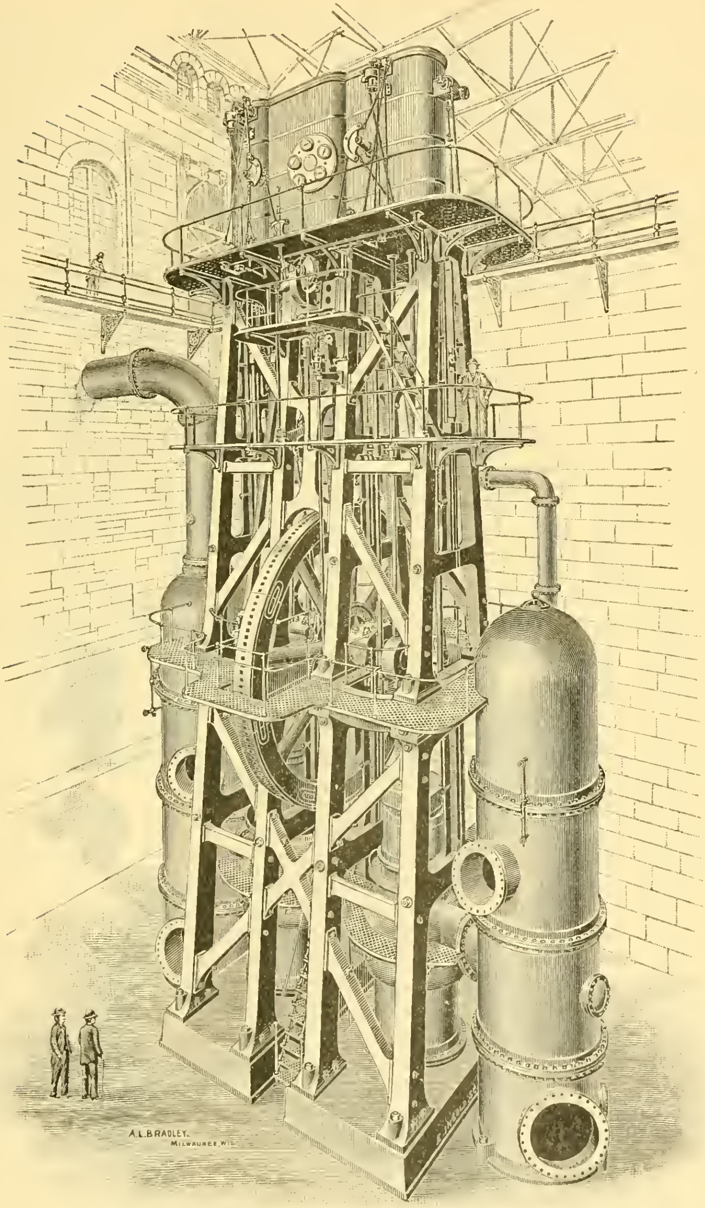


Fig. 7.

Four Vertical Compound Pumping Engines.

For St. Louis, Mo. Cylinders 27″ x 52″ diam. x 108″ stroke.

attachment. The governor controls only the high pressure cut-offs, and is arranged to control the engine at varying speeds, or limit it at a predetermined maximum speed. The cut-offs on the intermediate and low pressure cylinders are always adjusted by hand, and require no adjustment for changes in load, unless possibly for extremely wide changes where, for instance, fire pressure is put on the engine which is double the normal pressure, in which case a slight lengthening of the cut-offs would be desirable.

The throttle valve, cut-off adjustments, injection valves for condenser, etc., are all grouped together so that even the largest engines can be started by one man without difficulty.

The pumps, which are located beneath and directly in line with the steam cylinders, are usually of the single acting outside packed plunger type. The pumps are cylindrical in form, and usually arranged so that one end of the main bed plate of the engine is carried on top of the pump chambers (see Fig. 5), the other end of the bed plate being supported by a masonry pier. This arrangement reduces the cost of the foundation about one-third, and at the same time renders the pumps much more accessible. It has sometimes been criticised on account of the supposed difference in expansion between the masonry pier and the cast iron in the pump chambers, but the majority of our engines built during the past ten years have been arranged this way, and I have yet to see the first evidence of any difference in expansion, nor has there ever been any complaint on this score.

The air pump is driven directly from one of the plungers, as is also the feed pump and small air compressor for charging the chambers, so that there are no auxiliary pumps of any kind.

VERTICAL COMPOUND ENGINE.

The Allis vertical compound engine (Fig. 6) is built on the same general lines as the vertical triple, and is practically two-thirds of that machine, one cylinder, frame, bed, pump, etc., being omitted. Where it is necessary to use compound engines on direct service work, we ordinarily set the crank at 90°, and use differential plunger pumps in order to minimize the pulsation on the delivery main, although this can be accomplished by the use of air chambers. For reservoir work with compound engines we ordinarily use single acting plungers with the engine cranks set at 180° (Fig. 7). This

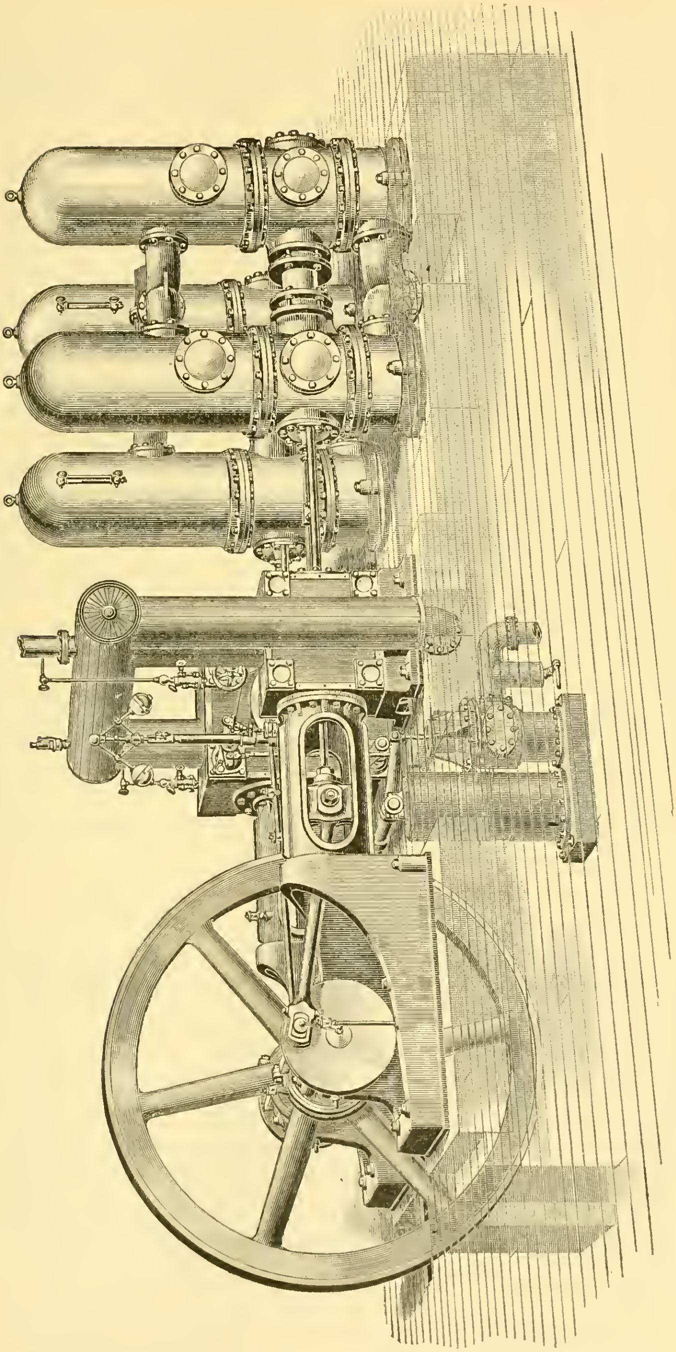


Fig. 8.
Horizontal Compound Pumping Engine.

simplifies the pumps, making a better balanced engine, and is in many ways more desirable than the differential type. The general features, such as valve gear, condensing apparatus, etc., are similar to the triple machine.

HORIZONTAL COMPOUND ENGINE.

The Allis horizontal compound pumping engine consists of a pair of cross-compound Corliss engines (Fig. 8) with two double acting pumps arranged tandem to the steam cylinders, the steam piston rods being extended through the back cylinder heads and coupled directly to the plunger rods. The engine cranks are set at 90°, which, with double acting pumps, gives practically a uniform flow of water. The pumps are usually the outside packed type, but occasionally for low pressures, where the water contains no sand, inside piston pumps are used. I regard this as the simplest and best form of horizontal pumping engine, as it is direct, easy of access, and inexpensive, and nothing more can be desired where a horizontal engine is to be used. The principal objection to this machine lies in the relatively large amount of space required. The horizontal engine is not, however, recommended excepting for small capacities under moderate heads.

The horizontal triple is not recommended excepting under very unusual circumstances, for it occupies a very large amount of floor space in proportion to its capacity, and when the cost of foundation, etc., is taken into account, the total cost of the horizontal triple is nearly as much as for the vertical triple, which is a decidedly better machine.

DETAILS OF ENGINES—STEAM VALVE GEAR.

All of our engines, (excepting the first pair built in 1873) have been fitted with Corliss valve gear, and in some cases poppet valves have been used on the low pressure cylinders. The Corliss valve, while theoretically imperfect, seems in practice to meet the requirements for all steam engine work (excepting for very high speed and marine engines) better than any type of valve that has yet been designed, and is fast becoming in American practice at least, the standard valve gear. Some of the advantages of this valve gear are that it has a nearly balanced valve, and one that remains practically steam tight. It is also capable of easy adjustment to se-

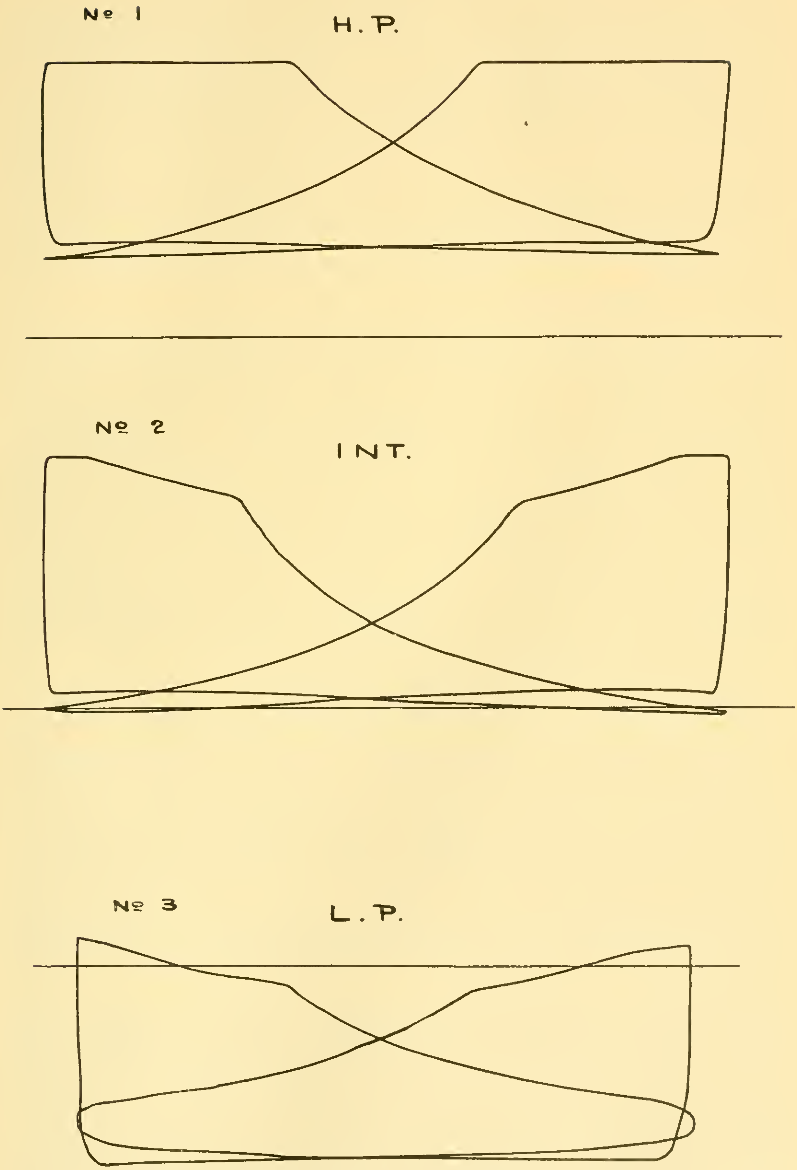


Fig. 9.

Steam Diagrams, from Triple Expansion Pumping Engine.

cure proper steam distribution, (Fig. 9) and on pumping engines can be adjusted while the engine is running. The valves are also easily removed without disturbing the setting of the valve gear.

The Corliss valve gear is essentially one in which the steam and exhaust valves are separated, i. e., each cylinder having two steam and two exhaust valves, and the mis-called Corliss valves, applied to some of the direct acting pumps, are merely rolling slide valves, which, being unbalanced, wear badly and require a great deal of lubrication.

It is now our standard practice on vertical engines, to place the valves in the cylinder heads, first with the object of reducing the port clearance, and secondly, to secure a simple form of steam jacketed cylinder. On the largest vertical engines we use poppet exhaust valves on the low pressure cylinder, and occasionally poppet steam valves on the low as well as poppet exhausts on both the intermediate and low. The use of poppet valves is for a two-fold purpose: First, to reduce the clearance to a minimum (3/8 of 1 per cent. in some instances), and secondly, to secure an absolutely tight valve, which would be very difficult with the light receiver pressure, and the large Corliss valves that would be necessary for 90-inch or 100-inch low pressure cylinders.

PUMP CONSTRUCTION.

Vertical pumps we usually build of the single acting outside packed type, as this is the simplest form, and as it has only one set of suction valves there is no difficulty with the pumps filling uniformly, while with double acting vertical pumps, particularly of long stroke, (see Fig. 7) the upper suction valves being usually several feet above the lower ones, the upper end of the pump may not fill as perfectly as the lower, particularly where there is a high suction lift.

Differential pumps we build for vertical compound engines for direct service work, where more uniformity of flow is desired than can be readily secured by two single acting plungers. In order, however, to obtain any advantage in the flow of water from differential plunger pumps, it is necessary to use at least a two-crank engine, and set the cranks at 90°, and I cannot see that the use of differential plunger pumps with single crank engines accomplishes any useful result, but on the contrary it compels the

construction of pumps requiring two sets of stuffing boxes or an inside sleeve, which is sure to leak. For this reason we use outside packed plungers wherever possible, thus securing the certain detection of leakage, and only use inside plungers or pistons on engines of small size working against low heads, and pumping water entirely free from grit.

The experience with the No. 3 engine at Chestnut Hill, Boston, shows what may be expected of unpacked inside plungers, even when working under very favorable conditions.

PUMP VALVES.

Our earlier engines were fitted with double seated brass valves of the so-called "Cornish" type, but in 1884 we fitted a pump with small rubber valves mounted on cages, which although designed originally only for pumping the very sandy water of the Missouri river under low head, were so successful as to lead us to adopt them as our standard type, to the exclusion of all others. The so-called cages are light octagonal or hexagonal iron castings, resembling very closely a hexagon nut. On the sides are mounted small rubber valves ranging in size from 2½-inch to 4-inch diameter, the sizes in most common use being 3-inch and 3½-inch diameter. In addition to the valves mounted on the sides of the cages, there are usually three or four on the top of the cage, each cage carrying from 15 to 35 valves, according to the size of the pump. There are usually 7 suction and 7 discharge cages for each pump plunger, and occasionally as many as 12 cages for very large pumps, or as low as three cages for small machines. Each cage is held in place by a single bolt extending downward through the center, tapping into a rib in the pump casting. As the pressure is always downward on these cages there is practically no strain on this bolt, and in a number of cases where the bolts have been practically twisted off by unnecessary strain when putting them in, the cages have worked for months, although the bolts were broken, being held to their seats only by the stickiness of the rubber gasket. The removal of this single bolt permits the entire cage to be lifted out for the inspection or removal of the valves, although they can be both inspected and renewed with the cage in position. The fact that nearly all of the valves are working on edge has sometimes been raised as an objection, but as the rubber valves are of

nearly the same specific gravity as water, their weight as far as any wear is concerned, may be entirely neglected, and in practice it is found that the valves on the sides of the cages wear as little as those on the top.

There can be no general statement as to the durability of these valves, much depending upon whether the water carries sand, and also on the composition of the rubber used, as this should be varied with every considerable variation in water pressure. I have in mind, however, two pumping engines, both of 18,000,000 gallons capacity, one working under 310 feet head and the other under 155 feet head, which have had the same set of rubber valves in use for over seven years, and the discharge valves are still so tight as to permit men to work beneath the delivery valves with the full water pressure on top of them.

For valve area we usually supply about 100 per cent. of the plunger area as the minimum, and running up to 125 or 150 per cent. for plunger speeds of 200 to 250 feet per minute.

It can hardly be said that there is any fixed speed proper for pumps, as different conditions demand different treatment, and while we have built pumps which are running successfully at 450 feet per minute plunger speed, and have several running entirely satisfactorily at 300 feet per minute, yet our experience leads us to advocate speeds of about 200 to 225 feet per minute for ordinary water works conditions. While high speed is quite possible, it is of more advantage to the builder of the engine than to the owner thereof. High piston speed adds but slightly, if any, to the steam economy, and usually adds considerably to the cost of maintenance of the engine.

The mechanically closed Riedler pump valve, which promised so much a few years ago, seems to have made but little progress in water works engines, at least in America. The few machines which have been built were mostly for underground work in mines, where the high speed engine was desirable on account of the small space required, but even in this field the automatic valve pump seems to be more satisfactory, as in some instances new engines of the automatic valve type are being placed in mines having previously used the mechanically controlled valve. In some cases the closing mechanism has been removed from these valves and the pumps found to work equally well without it, which leads to the

conclusion that the quiet working of these pumps at high speeds is due principally to the low lift of the valve. This brings us to the general proposition that moderately high speeds and smooth working can only be obtained by using valves of low lift, (and if of common construction, small diameter). The speed in feet per minute is not of itself of more importance than the number of strokes per minute, as the element of time plays an important part in the seating of a valve. The larger the diameter of the valve, the consequent greater lift required, and longer time for seating necessary, and the old idea of 100 to 120 feet per minute was largely due to the fact that the direct acting steam pumps used valves of comparatively large diameter, and their piston speed was maintained to the end of the stroke (instead of slowing at the end of the stroke, as with the crank engine), causing the valves to seat with a slam if operated at speeds much above 100 feet per minute.

In connection with the subject of plunger speed, the indicator diagrams shown in Fig. 10 may be of interest. No. 4 is from an Allis triple expansion engine; No. 5 from an Allis horizontal compound engine; No. 6 from Riedler valve pump (at Chestnut Hill), and shows nothing to especially recommend the mechanically closed valve. I do not consider, however, that indicator diagrams from pumps tell the whole story, for I have seen very "ragged" cards from pumps which, according to basin measurements, were working with less than 1 per cent. loss of action, while on the other hand, card No. 7 (from Louisville engine), which is practically perfect, was taken from the pump during a test on which the experts reported a loss of action averaging about $6\frac{3}{4}$ per cent. Our own experience with rubber valves of small diameter and low lift, working under suction lifts not exceeding 10 feet, is that the loss of action ranges between $\frac{1}{2}$ and $\frac{3}{4}$ of 1 per cent. This is based on both weir and basin measurements.

CONDENSING APPARATUS.

Our pumping engines are fitted with jet condensers, unless bad water or lack of water for condensing purposes renders the use of surface condensers desirable. Jet condensers are preferable in many ways, but where circumstances demand the use of surface condensers, great care should be taken to avoid getting grease in the boilers. Air and feed pumps are always driven directly from

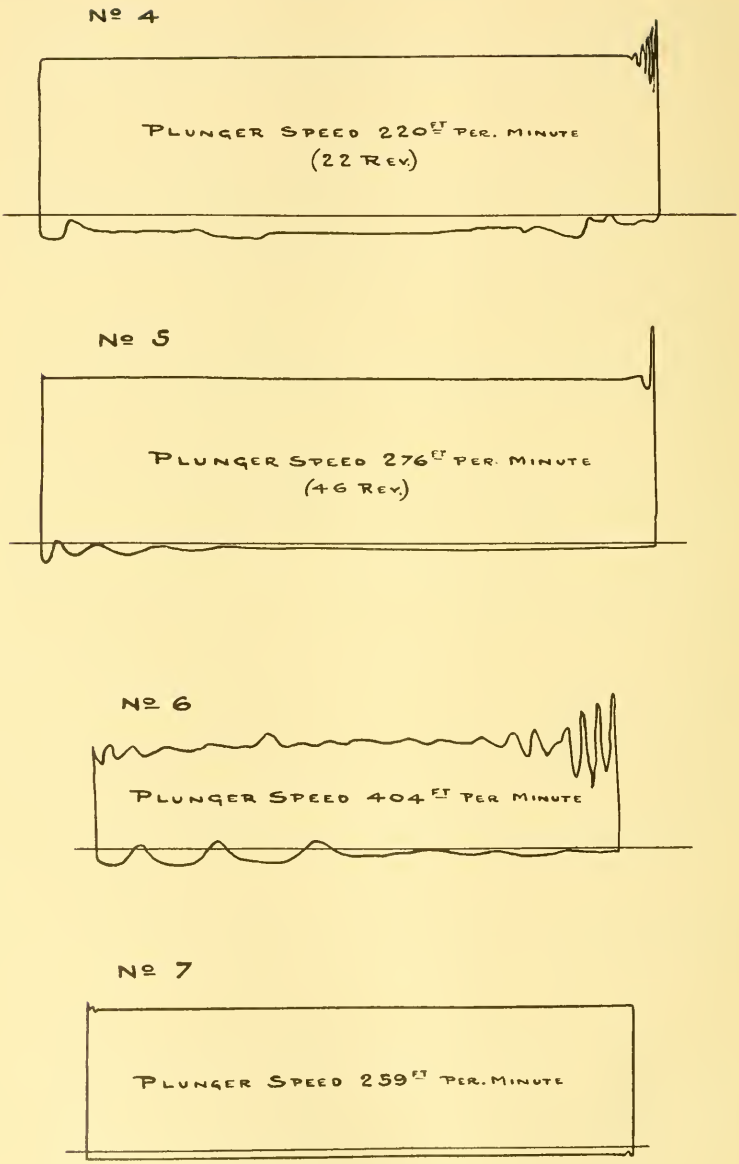


Fig. 10.

Pump Diagrams.

the main engines, and in vertical machines usually from the main pump plungers, and as there are no jacket pumps, the use of auxiliaries is entirely avoided, which, on account of the wastefulness of small steam pumps, etc., seems almost imperative if the highest results are to be attained. An illustration is seen in the No. 3 engine at Chestnut Hill, Boston. This engine, according to a test by Prof. Miller, showed the unequalled steam economy of 11.22 pounds of steam (actually supplied to the cylinders and jackets) per I. H. P. per hour, which, assuming that the boiler evaporated 10 pounds of water per pound of coal, corresponds to a duty of 160,000,000 on coal, but apparently the boiler evaporated about 10½ pounds, so that with 11.22 pounds of steam per I. H. P. per hour, and 10½ pounds of evaporation, the duty of this engine should have been about 168,000,000, while the duty on coal as reported was only about 150,000,000. In other words, the auxiliaries necessary for the operation of the engine, reduced the duty from 168,000,000 to 150,000,000, a loss of over 10 per cent.

BOILERS.

Not being interested either in the design or manufacture of boilers, my opinion as to the various types may be considered non-partisan. I do not believe that there is more than 10 per cent. difference in efficiency between any of the recognized standard types of boilers now in the market. Taking the ordinary horizontal tubular at 100, the best internally fired boiler would rate 105, and brick set water tube boilers at 95. The inferior efficiency of the horizontal tubular and water tube boilers, as compared with the internally fired boiler, is, I believe, almost entirely due to the radiation and air leakage in the brick boiler settings. There being so little difference in the efficiency of the boilers, the question becomes largely one of first cost, and details of mechanical design and construction. Where steam pressures of not over 125 pounds are to be carried, the ordinary horizontal tubular boiler answers every purpose, and all things considered, it is perhaps the most generally satisfactory. Higher steam pressures, however, render the adoption of water tube boilers, or the more expensive internally fired boilers, desirable. Internally fired boilers, to my mind, should be of the cylindrical type to avoid flat staybolted surfaces.

STEAM PRESSURES.

Marine practice has set the pace for higher steam pressures, due largely to the effort to produce the maximum H. P. with the smallest possible engine, and while high steam is undoubtedly desirable, it must be remembered that stationary engines are not subject to the same requirements as marine. The tendency, however, is rightly towards higher pressures, but for practical reasons I do not at present advocate the use of pressures much above 150 or 160 pounds, although as far as any economy is concerned, 200 or 250 pounds would be better. At 150 pounds, ordinary piping, valves, non-conductors, etc., can be used and no expensive or unusual construction is incurred, either in the boiler plant or engine, nor is special cylinder lubrication necessary. At higher pressures, however, everything becomes special, and the very slight increase in steam economy hardly warrants the extra expense and care incurred.

The question as to what steam pressure to carry, is one to be determined largely by the type of boiler selected. If ordinary horizontal tubular boilers are to be used, the steam pressure should not be over 125 pounds, although in extreme cases it is carried as high as 150 pounds. For pressures above 125 pounds, any of the various types of water tube boilers may be used, and if one is not limited as to the first cost of the plant, slightly higher efficiency may be obtained by using especially designed internally fired boilers. There is an erroneous impression that there is nothing to be gained by using triple expansion engines with steam pressures of less than 160 pounds. Our experience has shown, however, that with steam at any pressure above 80 pounds, the triple expansion engine will show an economy of from 10 to 15 per cent. better than a compound engine of the same general construction, using steam at the same pressure, and 75 per cent. of the triple expansion engines which we have built are operated with steam pressure of 125 pounds or less, the lowest being 80 pounds.

DUTY.

Next to reliability, the question of duty most interests the managers of water works.

While the coal duty in everyday service is the true test of efficiency of a pumping plant, (and also of the efficiency of its man-

agement), so many of the elements which go to make up this efficiency are entirely beyond control of the engine builder that it is hardly fair to make official duty trials on a coal basis, particularly as coal tests of less than 24 hours duration are practically valueless. Few engine builders are makers of boilers, and if they are the question of quality of coal, efficiency of firemen, draft of chimney, etc., so affect results as to render coal guarantees largely guess work. On the other hand, engine design has gotten to be a reasonably exact science, and builders can estimate the steam economy of any type of engine very closely. Therefore, it seems proper to make official duty trials on the basis of steam consumed by the engines, or on the heat unit basis recommended by the American Society of Mechanical Engineers. The work done should, in the case of outside packed plunger pumps, be figured on the basis of plunger displacement, after making proper test for leakage of valves, for the reason that with packed plungers the pump itself is a more accurate meter than a weir or Venturi meter.

The contention is frequently made that high duty engines fall very much below their test records on everyday service, and while in the majority of cases it is to be expected that the average duty would be somewhat less than that shown on a test, owing to the difficulty of watching all small matters on a continuous run which are looked after very sharply on a short test. But the greater part of the falling off in duty under everyday conditions is due to the fact that the engines are not run under contract conditions, either as to speed of the engine or steam and water pressures. The first is of much less importance than the last, for our experience has shown that a high duty engine running at one-half its rated capacity will give within 10 per cent. of as high economy as it will running at full capacity, provided steam and water pressures are kept the same. It is a very common, practice, however, when purchasing a pumping engine, to specify the maximum requirements as to water pressure, and the duty test is made under these conditions, while in regular service the water pressure may be 10 to 25 per cent. less than that originally specified. This means that in regular operation steam is carried at a considerably lower pressure, and the engine is throughout very much underloaded, and therefore necessarily uneconomical.

A properly designed pumping engine will work with water pres-

sures from 10 to 25 per cent. higher than the nominal pressures, without appreciably falling off in economy, but if the water pressures are from 10 to 25 per cent. *less* than the engine was designed for, the falling off in economy becomes very marked. It will, therefore, be seen that it is very important that specifications for pumping engines should call for the duty tests to be made under ordinary working pressures, the engines being guaranteed to work properly under maximum conditions. It is also desirable that the engine should be built as nearly as possible of the capacity required for ordinary work, for while not as important as the matter of water pressures, still, if the best results are to be obtained, it is desirable to have the engine run at approximately its rated speed. Of course on direct service work the speed of the engine must necessarily be subject to considerable variation between the hours of maximum and minimum consumption.

The efficiency of a boiler plant is very frequently not maintained to its full standard. More boilers are often operated than are actually required, thus burning less coal per square foot of grate than is economical, and there are numberless opportunities about the plant for wastes, which, while individually small, in the aggregate reach a very appreciable item.

In a general way, therefore, the falling off in economy under ordinary running conditions, is due not to faulty construction of the machinery, but the fact that it is operated under different conditions than those named in the specification, the requirements of which it was designed to meet. Therefore, the matter rests more in the hands of the purchasers of the machinery than in those of the builders.

It is unfortunate that the keeping of accurate records at all pumping stations is so rare, and the recommendation of your Association on this subject is to be commended.

What a modern high duty engine will do under regular running conditions is well shown by the record of an 18,000,000 gallon triple expansion engine in the Milwaukee Water Works, (See Fig. 11). This engine has been in service a little over seven years, averaging over 23 hours per day at full speed. It pumps about 70 per cent. of all the water used by the city, the remaining 30 per cent. being pumped by compound engines, the newest of which is 17 years old. The duty of the station on all coal burned for all

Fig. 11.

YEARLY RECORD OF THE MILWAUKEE 18,000,000 GALLON TRIPLE EXPANSION PUMPING ENGINE.

Started Aug. 23, (new)	1891.	1892.	1893.	1894.	1895.	1896.	1897.	1898.
Total hours run per year	1914	$6979\frac{1}{2}$	$8287\frac{1}{2}$	$8117\frac{1}{2}$	$8183\frac{1}{2}$	$8737\frac{1}{2}$	8005	$8666\frac{1}{4}$
Average hours run per day	$14\frac{7}{10}$	19	$22\frac{45}{100}$	$22\frac{25}{100}$	$22\frac{42}{100}$	$23\frac{87}{100}$	22	$23\frac{74}{100}$
Average gals. pumped per day for 365 days	10,870,000	14,250,000	16,700,000	16,500,000	17,830,000	19,750,000	16,360,000	18,445,000
Rate of pumping, Actual running time	17,750,000	18,000,000	17,850,000	17,800,000	19,100,000	19,850,000	18,000,000	18,650,000
Per cent. of total pumpage of station for year	16%	63%	65%	64%	$70\frac{7}{10}$%	$79\frac{6}{10}$%	$69\frac{3}{10}$%	$79\frac{1}{2}$%
Duty of station on all coal burned	80,428,800	99,043,000	101,481,000	103,342,000	103,165,000	104,552,000	105,125,000	109,172,618

Total cost to pump 1,000,000 gallons to reservoir ($157\frac{1}{2}$ foot head) for years 1897 and 1898, $3.88.

Total cost to pump 1,000,000 gallons one foot high for the years 1897 and 1898, $2\frac{47}{100}$ cents.

These costs cover all expenses for all engines at the station, including wages, coal, oil, repairs and supplies.

The effect of the higher duty of 1898 does not reduce the cost of pumping below that for 1897; for the reason that the price per ton for coal was higher in 1898 than in 1897, and further, the quantity pumped in 1898 was $2\frac{1}{2}$% less than in 1897, while the wages and other expenses remained the same.

Duty is based on all coal burned for all purposes including heating building, running shop engine during day, and electric light at night. No deductions for ashes.

Previous to August, 1891, all of the water was pumped by *compound* engines, and the annual duty of the station on good anthracite coal was about 80,000,000. The *triple* usually pumps about 70% of the water, most of the balance being pumped by a *compound* built in 1881. The duty of the station has risen about 35% since the introduction of the *triple*, and if all the water could be pumped by *triples*, the duty would probably be 50% higher than it was when the work was done by *compound* engines.

purposes, without deductions or allowances of any kind, in 1891 was about 80,000,000, all of the water being pumped by compound engines. The first year that the triple ran (pumping only 63 per cent. of the water) the duty rose to 99,000,000, and has since steadily risen until the year 1898, when it was 109,172,618 foot pounds per 100 pounds of coal burned, the coal being Youghiogheny slack, costing $1.78 a ton, delivered at the station, and carrying 14 per cent. ash. While this engine ordinarily takes steam from the same boilers which supply the compound engines, it recently became possible to separate it for a period of five weeks, (Fig. 12) and during that time the engine averaged $23\frac{72}{100}$ hours per day, running at full speed, and gave a duty of of above 122,000,000 foot-pounds per 100 pounds of coal. The cost of coal to raise 1,000,000 gallons $157\frac{43}{100}$ feet, was $95\frac{1}{2}$ cents, the coal per indicated horse power per hour being less than $1\frac{1}{2}$ pounds.

Fig. 12.

MILWAUKEE 18,000,000 GALLON PUMPING ENGINE.

Record for Five Weeks, July 31st to Sept. 3d, 1898.

Total days run	35
Total hours run	$830\frac{1}{4}$
Average daily run per day	$23\frac{72}{100}$
Total gallons pumped	632,893,750
Average gallons pumped per day	18,075,000
Average head pumped against	$157\frac{43}{100}$ feet
Total coal burned	679,500 pounds
Duty on total coal	122,291,111 foot pounds
Coal—Youghiogheny slack:	
Cost of coal per ton	$1.78 delivered at station
Total ash and clinker	95,096 pounds
Per cent. ash and clinker	14%
Pounds of coal to raise 1,000,000 gallons 157.43 feet high	1,074 pounds
Cost of coal to raise 1,000,000 gallons 157.43 feet	$95\frac{1}{2}$ cents
Pounds of coal to raise 1,000,000 gallons one foot high	$6\frac{82}{100}$ pounds
Cost of coal to raise 1,000,000 gallons one foot high	$\frac{6}{10}$ of 1 cent
Indicated H. P. of engine	540 (approximate)
Coal per I. H. P. per hour	$1\frac{1}{2}$ pounds
Cost of coal per I. H. P. per year running 10 hours per day, (5,480 lbs.)	$4.87
Cost of coal per I. H. P. per year running 24 hours per day, (13,152 lbs)	$11 69

When it is considered that this record is made by an engine which has been in continuous operation for seven years, without having the cylinder heads removed, or even the steam valves removed for examination, the result is certainly very good.

The yearly performance of the 5,000,000 triple at Brookline, Mass., given below, is also an example of what may be done with a high duty engine, although the fact that the Brookline engine is only operated about eight hours daily, is of course fatal to the best results on the basis of all coal burned during the year.

Record of Work Done at the Low Service Pumping Station of Brookline, Mass.

Year.	Gallons pumped.	Coal consumed in pounds for all purposes. No deductions.	Gallons per pound of coal.	
1890 ..	322,767,796	1,141,175	282.8	Direct acting low duty engine.
1891 ..	356,812,572	1,263,395	282.4	
1892....	390,593,090	1,351,032	289.1	
1893 ...	443 973,099	1,582,471	280.5	
1894....	481,633,366	998,107	482.5	Triple expansion engine, in use part of the time.
1895....	483,969,131	803,642	602.2	In use most of the time.
1896 ...	494,095,562	745,692	662.6	In use all the time.
1897....	508,174,048	761,826	670.0	In use all the time.

Average number of gallons pumped per day in 1897.......... 1,392,258
Coal required if old engine had performed this work.........1,791,238 lbs
Coal actually consumed.. 761,826 lbs
Coal saved...1,029,412 lbs

Under test conditions compound engines with steam from 100 to 125 pounds, 110,000,000 to 115,000,000 duty per 1,000 pounds of steam, is all than can be expected, although in a few cases where very high steam has been carried, or other conditions are particularly favorable, this duty has been very considerably exceeded, notably in the case of Mr. Leavitt's engine at Louisville and the four Allis compound engines at Pittsburg, (Fig. 6).

For triple expansion engines, with steam at from 90 to 110 pounds, duties of 120,000,000 to 130,000,000 may be easily attained, while with steam pressures at from 125 to 150 pounds, a triple expansion engine will easily run up to 140,000,000 to 150,000,000, and very probably with steam pressures from 175 to 200 pounds, under favorable conditions the triple will give 160,000,000 duty per 1,000 pounds of steam.

Just what the future will show in the direction of duty it is difficult to predict. The quadruple expansion engine using high pres-

sure steam would undoubtedly effect some increase in economy, but on account of the satisfactory mechanical construction of the present triple expansion engine, I consider the adoption of the quadruple as doubtful, until our steam pressures exceed 200 pounds.

Our present ideal is to produce a horse power on 10 pounds of steam, and if our boiler designers will give us an actual evaporation of 10 pounds of water per pound of coal, we shall have a horse power with one pound of coal, or approximately 180,000,000 duty on coal. But the case is something like the race for speed in steamship practice, and we have approached a very steep part of the ascending curve of efficiency, so that the last fraction of duty comes very hard.

To sum up, the increase in duty during the past 25 years has been due principally to the introduction of the compound engine and also the triple expansion engine, both carrying higher steam pressures than were general in former years. A considerable part of the improvement is due, not to any radical change in the general construction of steam engines, but to the more careful design of the many details which go to make up a successful machine.

The reduction in cost of pumping machinery has only followed the reduction in cost of all classes of machinery, and in fact nearly all classes of manufactured products, due to improved facilities for manufacture, and it does not now appear reasonable to expect any very material reduction in the cost of machinery of this class for many years to come, unless entirely different and cheaper designs are adopted.

DISCUSSION.

The President. The paper is now open for discussion.

Mr. Dean. I am not going to discuss the engine portion of Mr. Reynolds' paper, but wish to the boiler part of it. I think it is a great mistake to perpetuate the idea, which I consider a fallacy, that when you wish to use high pressure you must have a water tube boiler. What high pressure is, seems to be an uncertain thing, because some people say 125 pounds is high pressure, and some people say something else is. As for my own feeling, I think 125 pounds is pretty low. Now, I take the position that no man can give any reason why a horizontal return tubular boiler should be limited to 125 pounds, or even 150 pounds.

To show that it is not a question of insurance, I will say that a short time ago I wrote to the Hartford Steam Boiler Insurance Company, (and the letter was answered by the president), asking them if they would insure a 72-inch horizontal return tubular boiler for 160 pounds of steam, provided it was made of $\frac{1}{2}$-inch plates with drilled holes and butt longitudinal seams having inside and outside covering plates, and having a number of rows of rivets which would not go through both of the covering plates. The president wrote to me that if the boiler was made in this way with drilled holes and everything else as good as could be, they would insure the boiler for 160 pounds of steam. A few days ago I asked the engineer of another of the most prominent boiler insurance companies whether or not they had any notions or superstitions. He said he hoped not. Said I: "Do you object to insuring an 84-inch horizontal return tubular boiler with $\frac{1}{2}$ inch plates with a factor of safety of five referred to the ultimate strength." After a little talk he said, "No."

In 1890 there was read before the Institution of Engineers and Shipbuilders of England, (East Coast), by one man named Kilvington and another named Taylor, jointly, a paper in which they said that they had furnaces in marine boilers which were over $\frac{5}{8}$ of an inch thick, that had been in use for eight or ten years, and nothing had happened to them; that they had had furnaces in use for three years $\frac{3}{4}$ of an inch thick, carrying 160 pounds of steam, to which nothing had happened so far; and that they would not hesitate, if there were any occasion, to use furnaces 1 inch thick.

Now, we know that from theoretical considerations there isn't any reason why 1-inch plates are not just as safe as thinner ones, for the reason that the heat passes through a plate with tremendous facility; and the trouble is (if there is any trouble) to get the heat into the plate and to get it out. Of course, when there is oil on the water side of a plate, there is likely to be trouble. This trouble would be just exactly the same whether the furnace is 1 inch thick or less, for if it explodes it will do just the same thing. It is a good deal like the danger in carrying a high pressure; if a boiler explodes with a low pressure it will kill everybody around it and smash everything all to pieces, and that it is just what it will do in the other case. I think it is simply a question in boilers of the strain per square inch on the weakest part, and corrosion. One

very important thing about a boiler is to have it so made that you can inspect as much of the inside as possible, as well as the outside, and you can thereby see what is going on, and keep yourself safe.

There are some water tube boilers of 300 horse power units, that have 36-inch drums. These drums are just as likely to explode as a 36-inch boiler, and if they should explode they would do just the same damage.

So I fail to see why anybody should attempt to scare the public by saying that horizontal return tubular boilers are dangerous, when you get up to a higher pressure than 125 pounds. If you have a notion that half an inch plate is the thickest that you want to use, and you want to use a horizontal return tubular boiler, make your boiler so small that the strain per square inch will be what you think it ought to be. And there is a good deal in thinking what it ought to be rather than knowing what it ought to be. A factor of safety referred to the ultimate strength I do not think of any consequence; referred to the elastic limit, it is of some consequence. I think a factor of safety of two, referred to the elastic limit, would be enough, but of course none of us have quite the courage to use so small a factor, especially when we consider corrosion. I will call attention to the fact in connection with marine furnaces, that a few years ago, it was thought $\frac{5}{8}$ of an inch was the greatest thickness which could safely be used; but those engineers of whom I have spoken have gone beyond that without any disastrous results.

Mr. Smith. Mr. President, there has been one point brought up which I must say I cannot thoroughly agree with, and that is on the matter of using a single acting plunger on a vertical pump in contradistinction to using a double acting plunger on a vertical pump. As I understood the paper the reason assigned for that was that the flow of water would be greater at the bottom of the pump and less at the top. That, to my mind, is a simple matter, which can be easily overcome by a proper design in the vacuum chamber on the suction, and by a proper design of the valve area between the two pump tables, the two valve tables. I have in my pocket a card, which I would like to pass around, taken from a double acting vertical pump, from the top side, in fact I have one taken from both the top and bottom sides, and I fail to understand the force of

the statement which has been made. These cards were taken from a double acting vertical pump working against a pressure of 145 pounds.

Mr. Reynolds. In reply to Mr. Smith, I want to say that in this paper I referred particularly to very long stroke pumps working under high suction lift. Let us imagine a case where the suction lift to the bottom valves was 28 feet; how would the top of your pump fill on a 9-foot stroke engine?

Mr. Smith. I would say in reply to that, that a man who set a pump in any such manner didn't fulfill the conditions necessary in setting such a pump.

Mr. Reynolds. While the case as stated may be an extreme one, it is often approached in actual practice on western rivers, where the rise and fall amounts to from 50 to 70 feet. In such cases it is necessary to set the pumps in a pit at such depth as to place the suction valves within reach of extreme low water in the river. Many pump pits along the rivers are over 40 feet deep, those now under construction in Cincinnati being 85 feet deep, and the pits at St. Louis are 55 feet deep. With engines of the long strokes employed in some places, (6 to 9 feet) the pits would require to be 8 to 10 feet deeper if double acting pumps were used, and this increased depth of pit would mean a serious expense without any gain whatever as far as the action of the pumps is concerned, but on the contrary there would still be a difference of several feet in the suction lift between the top and bottom valves which would make an appreciable difference in the behavior of the two ends of the pump. The cards which Mr. Smith shows are excellent, and as his engine is one of comparatively short stroke, I believe, and doubtless working under very moderate suction lift, there is no reason why both ends of the pump should not fill perfectly, though with a single crank vertical engine of the type I understand he has, I fail to see any particular advantage in making the plungers double acting.

I think as I said before, Mr. Smith failed to notice that my original statement as to the objections to double acting vertical pumps, applied particularly to long stroke machines with high suction lift, and not to short stroke pumps under ordinary lifts, against which there is no particular objection.

Mr. Dean. Going back to the horizontal return tubular boilers, I made a statement recently before a number of mill men, that I did not think any such boiler with butt joints had ever exploded. I wrote to the president of the Hartford Steam Boiler Insurance Company asking him if he had ever known of such an explosion, and he replied that he never had. All these horizontal return tubular boilers that explode are made with lap joints, and they explode at the seam. Now, the Hartford Steam Boiler Insurance Company certainly knows about boilers that explode, how many explode, and all about them; and the president says so far as he knows, no boiler of that type which has been built with butt joints, has ever exploded. This should be a very impressive fact.

Mr. Reynolds. In reply to what Mr. Dean has said, I would say that I am not interested in advocating any particular type of boiler, and I think the inference that my paper is an "attempt to scare the public," on the horizontal tubular boiler question, for the benefit of the water tube boiler, is unwarranted. My own practice has been to use horizontal tubular boilers for all pressures up to 125 pounds, but in the west there is a strong feeling (I agree it may be largely a superstition, as Mr. Dean intimates), against using plates thicker than about ½ inch on this type of boiler. Perhaps the fact that most water in the west carries a considerable amount of lime and not infrequently mud, may have something to do with this feeling.

The vertical fire tube boiler which has been so successful in New England, has never gained any foothold in the west, owing very largely to the deposits of scale and sediment on the bottom tube sheets, although in cases where properly cared for, the vertical fire tube boiler has done well. Of course throughout New England the water is usually so good that the question of scale or deposit may be almost entirely neglected, but practice in different parts of the country naturally varies somewhat. But as a designer of pumping engines I shall not be particular as to the type of boiler which is used in connection with our engines, so long as it gives the highest results, and if our boiler makers or designers will guarantee the efficiency which Mr. Dean states was readily reached in New Bedford, we shall then get a duty on coal which both boiler and engine man may well be proud of.

Mr. Rockwood's name being mentioned, the president called upon him.

Mr. Rockwood. I am a guest, Mr. President, and it would be hardly wise for me to precipitate a compound engine struggle here. I was very much interested in the paper. I like to have a man say flatly what he believes, and then you know just where you disagree with him. I wish with all my heart that the big Allis pumping engine, now to be seen running at the Chestnut Hill reservoir pumping station, could be tried without its intermediate steam end, for it is my belief it wouldn't show any difference in the coal bill at all.

Mr. Reynolds. In answer to Mr. Rockwood, I would say that the opinions expressed in this paper are entirely personal ones, and are not necessarily accepted by the public. I think the same applies to what Mr. Rockwood has just said. (Laughter.)

THE APPLICATION OF GAS, GASOLINE AND OIL ENGINES TO PUMPING MACHINERY.

BY FREEMAN C. COFFIN, C. E., BOSTON, MASS.

[*Read Dec. 14, 1898.*]

During the past two years the use of gas, gasoline and oil engines in driving pumping machinery has been increasing rapidly. The adoption of this class of power in the Western or Middle Western states has preceded its application to pumping machinery in New England, especially for public water supplies. There are already a large number of public pumping plants in the former section driven by some form of internal combustion engine, while in New England there are as yet very few such plants. This may be largely due to two causes; one the lack of gravity systems by which so many of the small towns and villages of New England are supplied; the other the presence of natural gas in the former section which provides a cheap fuel for this type of engine.

It is evident that under present conditions and in the present status of steam power there is a field for the application of this type of engine to pumping water for places of moderate size. Wherever the amount of water to be pumped is such that some type of engine using steam expansively, or the so-called "high duty pumping machinery" is more economical than the compound condensing direct acting pumping engine, the internal combustion engine now actually on the market is no competitor.

Wherever the compound condensing direct acting engine which has given and is giving such admirable results in places of moderate size, would be used, it is perhaps an open question whether to adopt that type or a gasoline or oil engine and power pump, except in cases where a steam boiler plant is already established and in operation, then steam pumping machinery would be the most economical. For very small plants the internal combustion engine has advantages that in many cases must cause its adoption where a comparison is carefully made.

There is apparently no question of the feasibility of using this type of power for pumping. It is not in the experimental stage but it is settled by experience that it is safe and certain in operation if an engine of good design and construction is used.

It is not the purpose of this paper to discuss the theory of the internal combustion engine or to enter into a lengthy description of it. Those wishing to consult a treatise on these engines are referred to "The Gas and Oil Engine" by Dugald Clerk.

A few of the general characteristics of these engines will be briefly mentioned.

The gas and gasoline engines are practically alike in construction and operation, the same engine can be used with either fuel, a few alterations being required in the arrangement when the fuel is changed. The oil engine is similar in general appearance and operation but the treatment of the fuel in the engine differs from that of gasoline.

In a gas engine the gas is introduced into the cylinder and mixed with air which is drawn through a valve into the cylinder by the outward stroke of the piston, the mixture is compressed by the return stroke and fired by an electric spark, or an ignition tube.

The cylinder is open on one end. The explosion of the air and gas behind the piston drives it forward and imparts the energy to the fly wheel, which is very heavy. There is but one explosion in two complete revolutions, the return of the piston forcing the gases formed by the combustion out at the exhaust, the next forward stroke drawing in the air and admitting the gas and the return stroke completing the cycle of work and compressing the charge for the next explosion. The gasoline engine works in precisely the same way except that the fuel is forced in by a pump worked by the revolution of the engine and is turned to gas within the cylinder or combustion chamber before mixing with the air.

The principal difference in the working of the oil engine is, that the fuel not being as volatile as gasoline, is introduced in a fine spray to a vaporizer where it is turned into vapor by the heated walls and then mixed with air. The vaporizer must be heated by a special lamp before starting the engine; this requires from seven to ten minutes, and therefore the oil engine requires that much more time to start it, than the gas or gasoline engine, which simply requires the supply cock to be opened, a few turns to be given to the

fly wheel and it is off, if there is no difficulty with the battery which provides the spark for firing. This seems to be the weak point in the gas engine, at least the only difficulty that I have seen in starting and running them seems to be connected in some way with the battery. Some of the oil engines require no battery, the charge is ignited after the engine is started by the heat of the walls of the vaporizer in combination with the pressure produced by the return of the piston. I can not see that the gasoline is superior to the oil engine nor vice versa, each have their points of superiority and each have slight defects. The cost of fuel is probably slightly less in the gasoline engine, while the use and storage of kerosene stands higher in popular favor. All engine cylinders are jacketed and a stream of cold water is passed around them, about 10 gallons per H. P. per hour are used with the oil engine.

The waste gases are exhausted into the air and if the exhaust pipe is carried above the building very little odor is noticeable. The exhaust is noisy unless muffled in some way. The speed of these engines is from 200 to 400 revolutions per minute, according to the size, and the main shaft can be connected directly to the pinion shaft of a power pump. It is necessary to use a friction clutch for this connection, as this type of engine must be started light and the load applied after it has acquired its speed.

ATTENDANCE.

Perhaps the most important feature in the operation of internal combustion engines is the attendance. Anyone with ordinary intelligence and no training as an engineer, can be taught in a short time to run one. In a well designed plant, properly supplied with large oil cups, the necessary attendance is limited to starting the engine, providing a sufficient supply of fuel in the tank and oil in the cups and stopping it at the proper time. Starting under ordinary conditions requires from a minimum of one minute with gas or gasoline engines to a maximum of fifteen with oil engines.

The speed of these engines seems to be most perfectly regulated by the governor which controls the supply of fuel, a sudden variation in load making but slight change in speed. If a main should break in front of the pump the speed would hardly vary 10 per cent. On the other hand, there is very little adjustment of speed possible. About 15 per cent. from the rated speed either

way is as much variation as can be obtained. If a pumping plant were required in which the running capacity could be reduced 50 per cent., it would be necessary to use two small pumps, one each side of the engine, with the friction clutches, either or both pumps could be run. As the engine so readily adapts itself to a change of load a pump could be thrown on or off at any time. These engines run very economically with a small load.

In writing the foregoing I have described the engines as I have found them in my own experience, and through the investigations that I made before recommending their use.

Very recently, however, a pamphlet has come into my hands. written by a Western man, presumably an engineer, although it is not so stated, in which a very strongly adverse opinion of internal combustion engines is expressed and a severe attack made upon oil engines through a certain make of that type. The writer of this paper has no acquaintance with the make of engine thus criticized.

It would seem from a reading of the pamphlet that no engines of that kind have ever been run successfully and the conclusion is drawn, that no internal combustion engine can be successful. This conclusion seems to be contrary to the general experience, as I have found it among the users of these engines. Occasional difficulties will no doubt be met, but with a first-class engine of sufficient capacity for its work and properly erected I believe its performance will generally be satisfactory.

Certainly no plant of this kind should be installed without a careful study of all of the conditions and a comparative study of a steam plant for the same service.

CONDITIONS OF PUMPING UNDER WHICH INTERNAL COMBUSTION ENGINES OFFER ESPECIAL ADVANTAGES.

Wherever it is desirable to have a pumping plant run by the superintendent of the works, or by some one who has other duties to perform, the small amount of time required for attendance and the fact that a skilled or licensed engineer is not required tells strongly in favor of these engines when compared with steam.

Where a needed additional supply of water can be secured at some place too remote from the existing pumping station to be pumped by that plant, the smaller first cost and possibility of running the new plant without occupying the full time of an engineer

would naturally lead to the adoption of this type of engine. Where an extra supply is needed for a few months in the year a pumping plant can be installed at a low cost that will do satisfactory and economical work at less annual expenditure for fixed charges.

When a suitable and sufficient supply can only be obtained by developing two or more sources as large springs or limited driven well supplies, a plant of this kind can be installed at each place at moderate cost and run by the same person.

High service supplies where the high service pumping cannot be done at the main station or where the low service is supplied by gravity.

A pumping plant of this type seems peculiarly adapted for use in a sewerage system where the topography requires that the sewage be collected and pumped at two or more points in order to avoid great expense of construction. As the lift is generally light the total power required is small and even in fuel consumption these engines would compare favorably with a very good type of steam engine.

I believe that its merits demand an economic comparison with steam power in any plant where the amount pumped does not require a high duty engine.

Every case must be decided upon its own merits and I am far from believing that these engines will supplant steam or from recommending them in any sweeping manner, however desirable they may be under certain conditions.

During the past season the writer has installed two pumping plants driven by oil engines. The oil engine was chosen in both cases, not on account of any apparent superiority over the gasoline engine, but because the parties interested preferred the storage and use of kerosene to that of gasoline, although realizing that the cost of fuel would be somewhat more with the former.

The cost of a first class engine of either type when installed with all appurtenances did not differ materially at that time and for those sizes.

COHASSET WATER WORKS PLANT.

The first of the above mentioned plants to be installed was for the Cohasset Water Company. This plant was to pump a small additional supply from driven wells. The available supply was

thought to be sufficient, in addition to the original one, for several years, but not large enough to warrant much outlay, therefore the plant was put in with as little expense as possible. A vertical triplex single acting pump was used. The plungers were $6\frac{1}{2}$ inches in diameter by 8-inch stroke with a capacity of 150 gallons per minute at its normal rate of speed. The pump was of an inexpensive type with outside bearings on the main shaft and plungers of the trunk pattern, with no cross-heads and the connecting rod hinged to the bottom of the plungers. It has, however, given very satisfactory results running without attendance throughout the season. It was built and erected by the Geo. F. Blake M'f'g. Co.

The engine was a Hornsby-Akroyd oil engine rated at 13 H. P., built and erected by the De La Vergne Refrigerating Co. The engine shaft was directly connected to the pinion shaft of the pump by a friction clutch.

ACCEPTANCE TEST.

The engine was guaranteed to develop at least 13 H. P. with a consumption of 1 pound of oil (150° test) per H. P. per hour. The pump was guaranteed to give 70 per cent. efficiency. The engine was first tested alone by an absorption brake, the test resulting in the development of nearly 15 H. P. with a consumption of 0.926 pounds of oil per H. P. per hour. The combined plant was then tested under as nearly as possible the same condition as in the brake test, the water pumped and the total lift being taken as the measure of the work. This test resulted in a consumption of 1.323 pounds of oil per H. P. per hour, based upon the foot pounds of work done in actually raising water. Assuming 1 pound of oil per H. P. as the performance of the engine the efficiency of the pump was nearly 76 per cent. Assuming that the engine was doing the same as in the brake test or developing one H. P. for 0.926 pounds of oil per hour the efficiency of the pump was exactly 70 per cent. It was perhaps remarkable that this should have been precisely the same as that guaranteed but I can only say that there was no juggling with the figures. The performance of the entire plant was about 8 per cent. in excess of the guarantee.

This plant was started May 31, 1898, and stopped for the season October 26th, and run during that time 115 days, pumping an

average of 103,600 gallons per day, or a total of 11,914,000 gallons. Deducting the amount of water used for cooling (estimated from measurements made during the test) or 173,000 gallons, the effective pumping was 11,741,000 gallons, the average lift was about 160 feet.

The total amount of oil purchased was 1,745 gallons, assuming that the engine consumed 1 pound per H. P. per hour the efficiency of the pump was 70 per cent. or about 8 per cent. for the entire plant, less than during the test.

The number of gallons pumped per gallon of oil was 6,728. The weight of oil sold as one gallon by the Standard Oil Co. is 6.5 pounds.

The attendance given this plant was limited to starting the engine in the morning and as the oil cups were rather small, oiling at noon and shutting down at night, through the day the building was locked up.

The cost of this plant, exclusive of building and foundation, was very nearly $1,500 erected, including gauges, connections, etc.

WINCHESTER OIL ENGINE.

This plant was installed for the high service system of the Winchester Water Works. The pump is vertical triplex single acting with $8\frac{1}{2} \times 12$-inch plungers, and a capacity at its normal speed of 350 gallons per minute or 500,000 in twenty-four hours. Each plunger has a guided cross-head, there is a crank on each end of the shaft and overhung from the frame which carries the main boxes, the third crank is between the frames. It is one of the best types of vertical triplex pumps.

The engine is a 20-H. P. Hornsby-Akroyd oil engine; this power is 40 per cent. in excess of the actual work to be done under the requirements or 14 per cent. in excess of the power required to drive the pump if the latter has an efficiency of 80 per cent.

The entire contract was taken by the Goulds M'f'g. Co. whose guarantee was that the plant should be able to pump 350 gallons per minute against a total lift of 160 feet with a consumption of oil not exceeding 1 pound for each 10,750,000 foot pounds work done.

This plant was recently tested by Mr. J. W. Mackie representing the Goulds M'f'g. Co. and the writer.

The results of the test were as follows:

Duration of test		5 hours
Average head pumped against	142.6	feet
Total number of revolutions	12,007.	
Revolutions per minute	40.	
Displacement per revolution	8.843	gallons
Displacement per minute	354.	"
Total displacement in gallons	106,182.7	"
Slip past plungers (measured)	20.	"
Net amount pumped neglecting slip of valves	106,162.7	"
Weight of water	885,397.	"
Total work	126,247,598.	ft. lbs.
Average power (measured by water pumped)	12.75	H. P.
Total fuel (150° test kerosene oil)	70.69	lbs
Total fuel	10.876	gallons
Consumption of oil per H. P. per hour	1.11	lbs.
Consumption of oil per H. P. per hour	0.171	gallons
Work done per pound of oil	1,771,772.	ft. lbs.
Work done per gallon of oil	11,516,518.	ft. lbs.

The latter figure was 7 per cent. in excess of the contract requirement of 10,750,000 foot pounds for each gallon of oil consumed.

Although there was no requirement as to the relative efficiency of the engine and pump, it was understood that the engine should develop one horse power per pound of oil per hour, and that the pump should show an efficiency of not less than 80 per cent. of the power furnished it by the engine.

No brake test has yet been made, but if it is assumed that the engine consumed 1 pound of oil per H. P. per hour then the pump would have an efficiency of a little more than 90 per cent. If on the other hand an efficiency of 80 per cent. is assumed for the pump, the engine was developing one horse power with a consumption of a little less than 0.89 pounds of oil per hour. The head pumped against during the test was the ordinary working head. Another run was made, however, that showed the plant to exceed the capacity requirement of the contract which was 350 gallons per minute against a total lift of 160 feet. The plant was run at that rate against a head of 186 feet, showing available power 16 per cent. in excess of the requirement.

The amount of water used for cooling during the test was 8.2 gallons per H. P. of actual work done or about 6.8 gallons per H. P. developed by the engine.

It may be noted that the engine was developing but little over 15 H. P. during the test or about three-fourths load; the result might have been still higher if the full 20 H. P. had been developed.

The cost of this plant, exclusive of building and foundation, was about $2,900, including piping, erection, gauges, etc. Oil cost here at the present time 7¾ cents per gallon delivered in 300 gallon lots.

A SEWAGE PUMPING PLANT.

The internal combustion engine seems peculiarly adapted to the conditions of pumping in some sewerage systems and although not yet built, a brief description will be given of a plant, which has been designed by the writer for the sewerage system of the City of Charlottetown, Prince Edward Island. The sewage from the central portion of the city can be discharged by gravity ; this part of the system is being built this season. There are two sections, one on each side of the city, from which the sewage must be pumped. The estimated flow from one is 100,000 gallons per day, from the other 150,000 gallons. It is impracticable to collect the sewage of both these sections at one point on account of the expensive deep cutting between. A small storage reservoir is designed for each section, with a pumping plant consisting of a gas engine and two centrifugal pumps at each station; the size of one pump to be about equal to the power of the engine, the other one-half that size. With the smaller one the pumping may go on nearly continuously, using the reservoir as a margin for either an excess or deficiency of flow of sewage, as compared with the capacity of the pump.

The larger pump will be used, if it is desired to pump at certain stages of the tide, or occasionally if the flow is greater than the capacity of the small pump. A recording device will show in the office the height of the sewage in the reservoirs. It is expected that the pumping machinery can be looked after and the pumping done by the man who inspects the sewers and attends to the ordinary flushing.

The pumping plant will be stopped automatically, when the sewage in the pump well is drawn down, by the action of a float, in shutting off the fuel supply of the engine. The attendance will consist in starting the engine and keeping the oil cups filled. Gas

will probably be used, as the price of gasoline is high in this place. Gasoline can be used, however, in the same engine by making a few changes and continuous pumping will not depend entirely upon the gas supply.

These plants will probably be installed the coming season.

COMPARATIVE COST OF PUMPING.

From the results secured in my experience it is estimated that a well designed oil engine plant will in regular duty raise 1,000,000 gallons one foot high for each gallon of oil consumed.

This allows the engine one pound of oil per H. P. per hour and the pump an average efficiency of 65 per cent. This I believe to be a conservative estimate of the results to be secured.

From tests made by others which there is not the space to quote here, it is estimated that a first class gasoline engine plant will do the same amount of work with a consumption of 0.9 gallons of fuel.

There is so much difference in the quality that it is difficult with the data available to make an estimate of the consumption of gas. A safe estimate, however, is that 130 cubic feet of good city gas will do the same work as a gallon of oil, or raise 1,000,000 gallons one foot high.

Upon this basis the fuel cost of pumping water will be as follows:

	With Oil at 9 Cents per Gal.	Gasoline at 9 Cents per Gal.	Gas at $1.00 per 1,000 Cu. Ft.
1,000,000 gals. one foot high...	9 cents	8.1 cents	13 cents

An estimate has been made with an endeavor to be as exact as it is possible to be in a general estimate, of the cost of installation of plants of different capacities of both types, steam and internal combustion engines, also cost of fuel, attendance, repairs, supplies and fixed charges. The steam plants estimated upon were of the compound condensing duplex direct acting type of pumping engines, with horizontal boiler and brick chimney, and small coal shed. The duties allowed such plants were estimated from the reports of water works, pumping similar quantities of water. The size of the plant of either type was such that the daily consumption could be pumped

in ten hours. The cost of the plants upon which the fixed charges are based includes the necessary buildings and foundations.

From these estimates diagrams have been prepared showing the annual cost of each item of expense and the total cost. The diagrams are based upon a dynamic head of 210 feet, this being an approximation to the average head in different places as given in water works statistics. The pumping is given as the amount pumped per day. While estimates of this kind must be used with caution in particular cases, they may be of assistance in the preliminary study of the subject. The following table gives total annual cost for certain rates of pumping:

Table Giving Comparative Annual Cost of Pumping With Different Types of Power.

Average Daily Pumping in Gallons.	Oil Engine. Oil at 9 cts.	Gasoline Engine. Gasoline at 9 cts.	Gas Engine.		Steam Pump.	
			Gas at $1.00.	Gas at $0.50.	Coal at $5.00.	Coal at $4.00.
50,000	$ 770	$ 735	$ 920	$ 675	$1,230	$1,160
100,000	1,275	1,200	1,580	1,035	1,740	1,600
200,000	2,200	2,050	2,815	1,820	2,525	2,300
300,000	3,085	2,875	4,000	2,510	3,130	2,850
400,000	3,920	3,640	5,140	3,150	3,700	3,350
500,000	4,745	4,400	6,270	3,780	4,200	3,790

The basis upon which these comparative estimates were made was certainly not unduly favorable to the internal combustion engine.

It is important that there should be a margin of power in this type of engine over the work to be done; if they are overloaded they will gradually slow down and stop entirely.

It is also necessary that a very rigid foundation should be provided, as the shock of the explosion tends to produce vibration unless the engine and foundations are very secure.

THE DIESEL MOTOR.

Although not included in the scope of this paper I wish to make a brief reference to the new engine or motor that has been brought out in Germany and is, I understand, now being built in this country, the Diesel Motor. This is said to be the most perfect heat engine ever made, and one that in many tests has given from 25 to

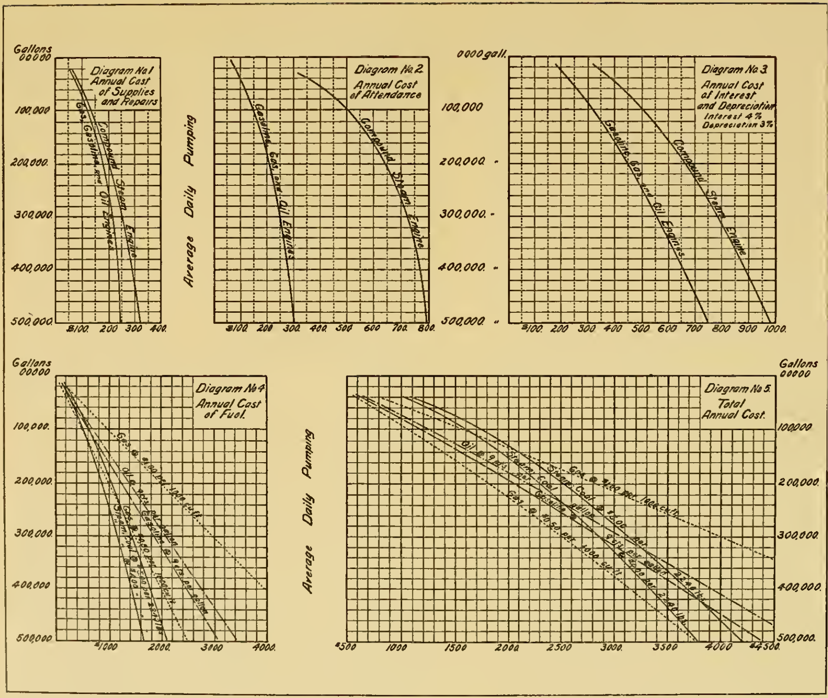


Diagram No 1
Annual Cost
of Supplies
and Repairs
Compound Steam Engine
Gas, Gasoline and Oil Engines
Diagram No 2
Annual Cost
of Attendance
Gasoline, Gas and Oil Engines
Compound Steam Engine
Diagram No 3
Annual Cost
of Interest
and Depreciation
Interest 4%
Depreciation 3%
Gasoline, Gas and Oil Engines
Compound Steam Engine
Diagram No 4
Annual Cost
of Fuel
Diagram No 5
Total
Annual Cost
Average Daily Pumping
Gallons
100,000
200,000
300,000
400,000
500,000

30 per cent. efficiency of the total heat energy in the fuel, as compared with 18 to 19 per cent. in the best gas engines, 16 to 17 in the best oil engines and 10 to 12 in the best steam engines. The fuel used is petroleum. If this engine has the advantages and economy that are claimed for it, it must have a notable influence upon the production of power.

A COMPARISON OF COMPOUND AND TRIPLE EXPANSION ENGINES FOR SMALL WATER WORKS PLANTS.

BY J. M. BETTON, ASSOCIATE MEMBER N. E. W. W. ASSN.

[*Presented Dec. 14, 1898.*]

The attention of water works superintendents and engineers has been drawn for the past few years to the question of economy in water works management. Every item of expense has been closely calculated and, by comparison with the work of others, made known through an interchange of experiences, they have reached astonishingly low results.

In no one direction has there been developed a greater opportunity for saving in the general operation of a pumping station than in the cutting down of the coal pile.

The problem of saving coal in cities and towns pumping a sufficient quantity to justify an expenditure for a high duty engine is comparatively easy of solution, but the desire and necessity of saving coal is no less in small towns where the consumption is light, while the proposition is much more difficult as the income will not justify an expenditure for refined machinery and the old pump must be kept at work, although it may be a coal eater and a bane to the life of the superintendent. In this unhappy condition the thoughtful manager of a small water works eagerly asks: "What can I do to economize in coal?" What pumping engine is there of small capacity, not beyond us in cost, and of fair economy that I can recommend to my board of commissioners as showing sufficient saving to justify the expenditure.

It is evident that the standard compound engine as made by various manufacturers of pumping machinery throughout the country does not meet this requirement.

He finds these engines of varying degrees of excellence, depending upon the care and skill with which they are built and erected, but of substantially the same design, as they are all modeled closely

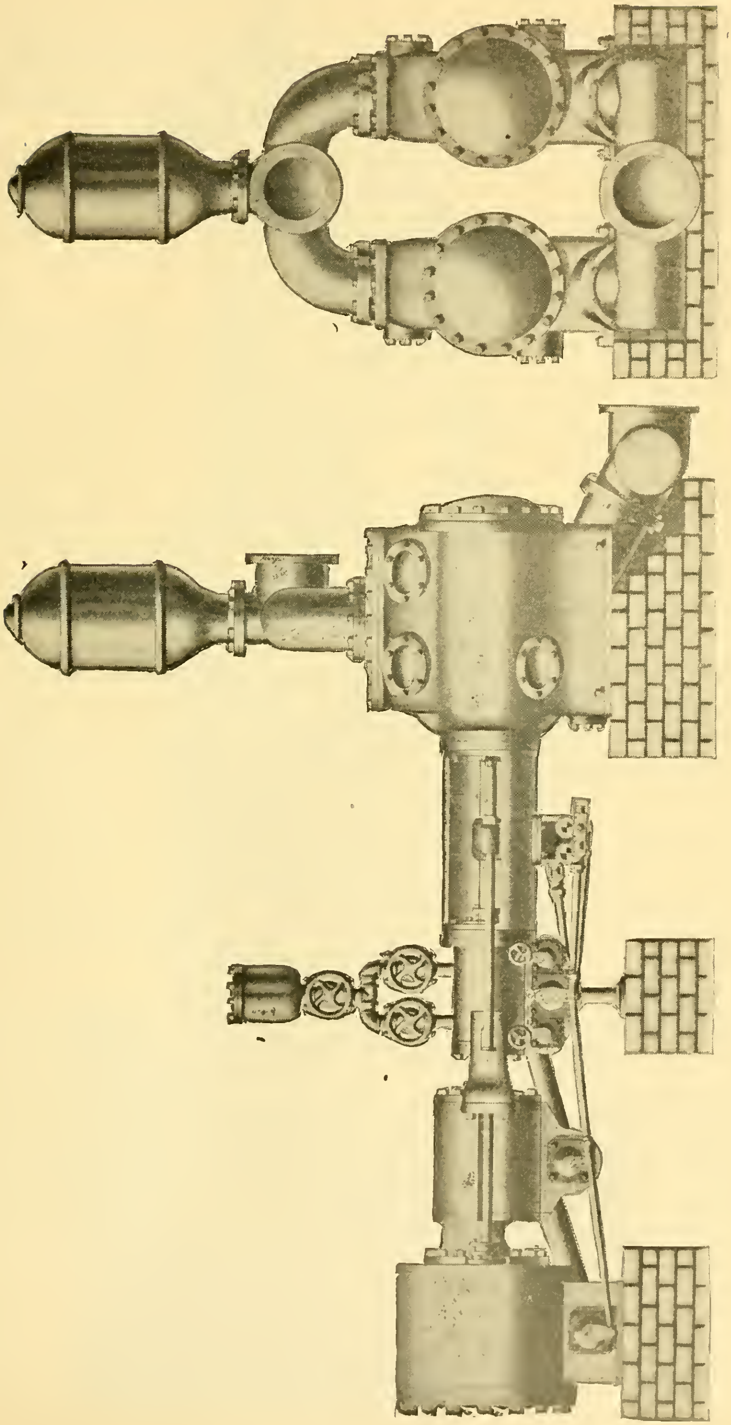


Fig. 1.

from the original Worthington Duplex Compound Engine of thirty years ago; and as he contemplates their running record of 25,000,000 or 30,000,000 duty, where he has hoped for 60,000,000 or 70,000,000, his case looks hopeless, at least in this direction.

It is to meet just this often expressed desire for a more economical engine of small capacity that Henry R. Worthington have brought out their Standard Horizontal Triple Expansion Engine. (Fig. 1.)

The problem before them was this:

An engine so simple in design that it could be built at low first cost and yet possess the refinements of a triple expansion engine capable of showing a coal saving that would justify its use when pumping a comparatively small quantity of water, and prove, as well, durable and free from repairs.

The purpose of this paper is to show you the design of this engine and to ask you to follow me in a brief calculation as to the results obtained by those now in use to see if the requirements have been successfully met.

The engine is of the 6-cylinder type having the cylinders arranged in tandem with the low pressure on the outside. (See Fig. 2.) At the first glance the objection might be raised that this arrangement made the engine inaccessible and that the pistons could not be removed without effort or else dismantling the engine. By referring to Fig. 3, however, you will see that by a patented arrangement of rods, the difficulty is overcome and each piston or cylinder may be inspected without dismantling or removing anything but the necessary head. The high pressure piston comes out between the high pressure and intermediate pressure cylinders, as does the intermediate piston, the low pressure piston being drawn at the back.

The steam valves (in nearly all cases) are of the Corliss semi-rotative type and are placed beneath the cylinders. (Fig. 4.) The advantages of this type of steam valve over the slide or grid-iron pattern are too well known to need discussion, but I should like to call your attention to the advantage gained by placing these valves beneath rather than on top of the cylinders. This insures a perfect drainage of the cylinders, as any moisture carried over by the steam does not enter the cylinder but is carried out at once

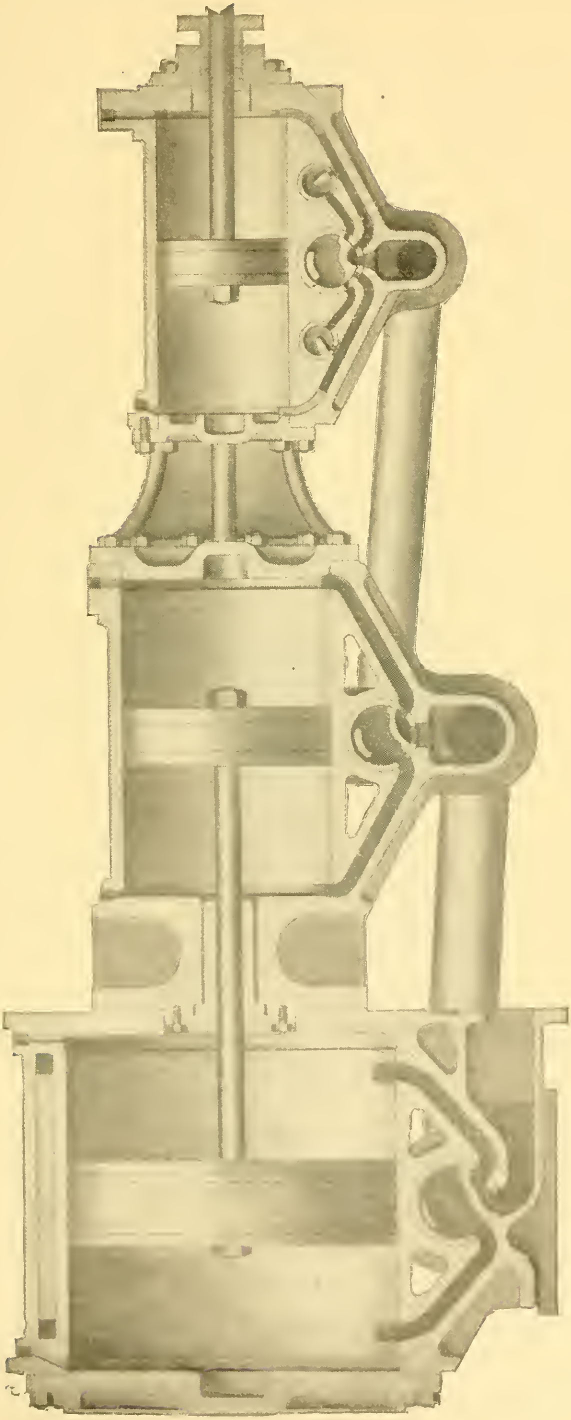


Fig. 2.

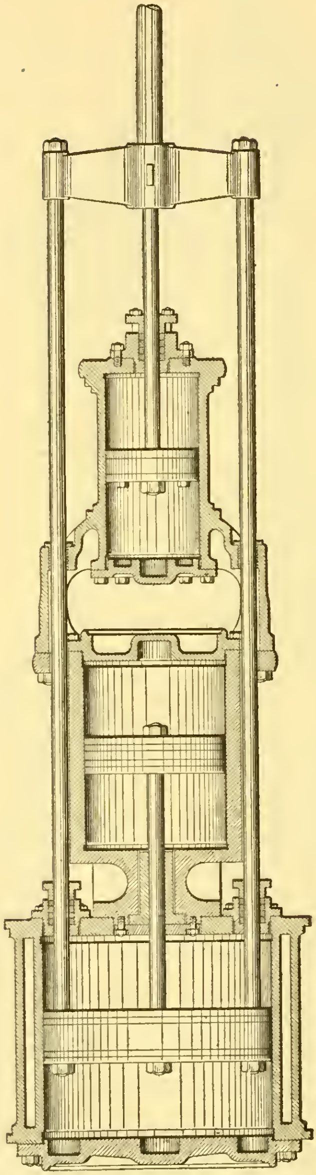


Fig. 3.

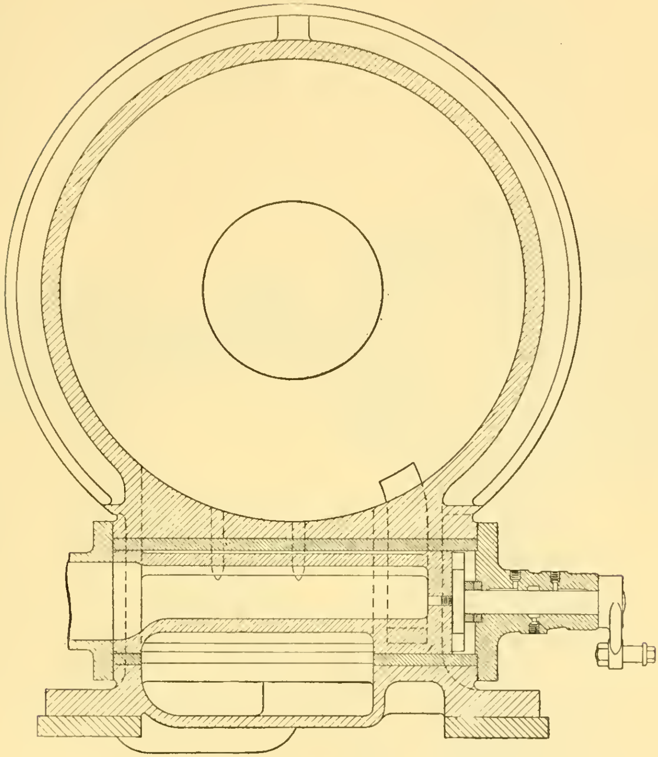


Fig. 4.

through the exhaust. In fact since adopting this arrangement, it has been found that it is entirely unnecessary to use drip valves or drains of any kinds on the steam cylinders. The cut-off valves are placed on the high pressure cylinder only and are set to cut off from ½ to ¾ of the stroke.

Now as to economic results: It is a well known fact that the maximum duty obtained with the compound condensing direct acting engine (Fig. 6) is in the neighborhood of 50,000,000 to 70,000.000 foot pounds, depending upon its size, and an engine of this type that can steadily maintain such results is certainly making a good showing. With the triple, however, there is no difficulty in attaining and maintaining duties of from 70,000,000 to 100,000,000.

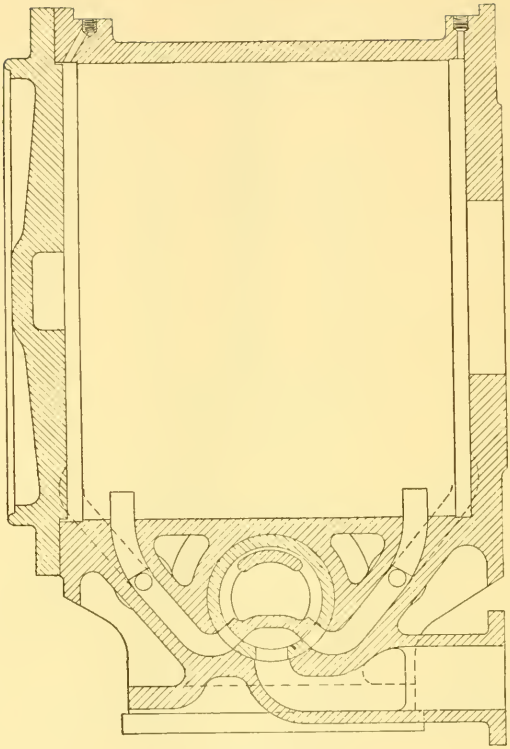


Fig. 5.

During the past year there have been installed upward of 20 of these engines of capacities ranging from 750,000 to 5,000,000 gallons per 24 hours when pumping against heads of from 20 to 1,000 feet.

At the Vulcan mine in Michigan the engine is delivering 1,200 gallons per minute against a pressure of 1,000 feet, and on the official trial showed a duty of 92,000,000 foot pounds per 1,000 pounds of dry steam. Subsequent tests of this engine made under every-day running conditions by the mine engineer have shown a duty of over 80,000,000 foot pounds, based on actual water evaporated in the boiler, no allowance being made for the condensation in 1,200 feet of steam pipe.

At Concord, N. H., the engine is of 2,000,000 gallons capacity,

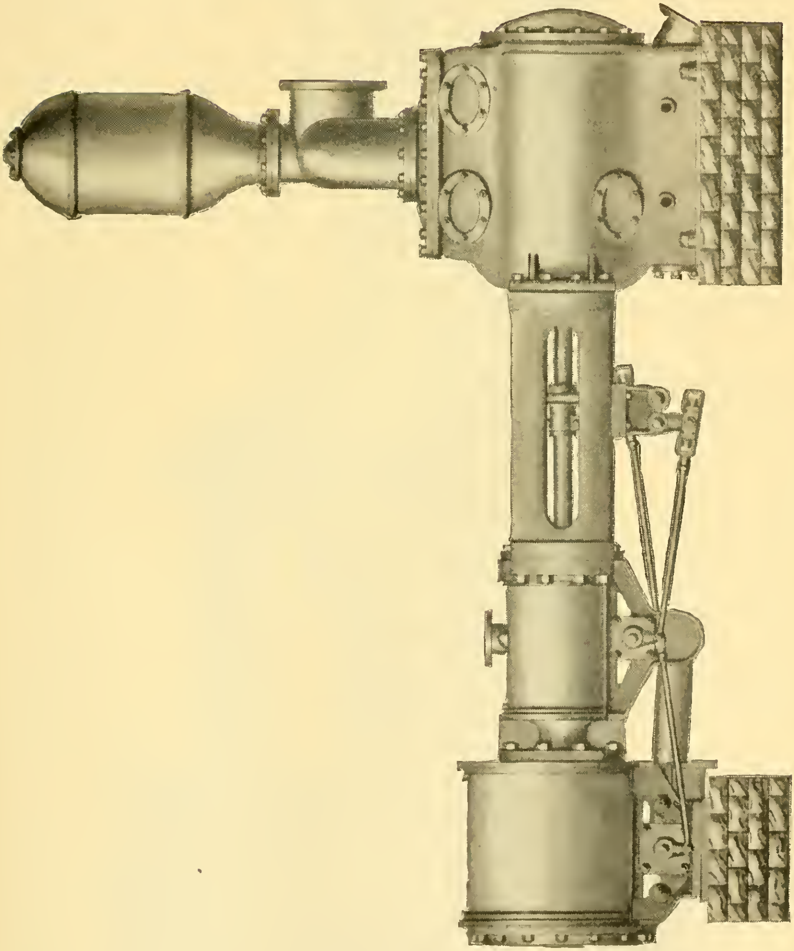


Fig. 6.

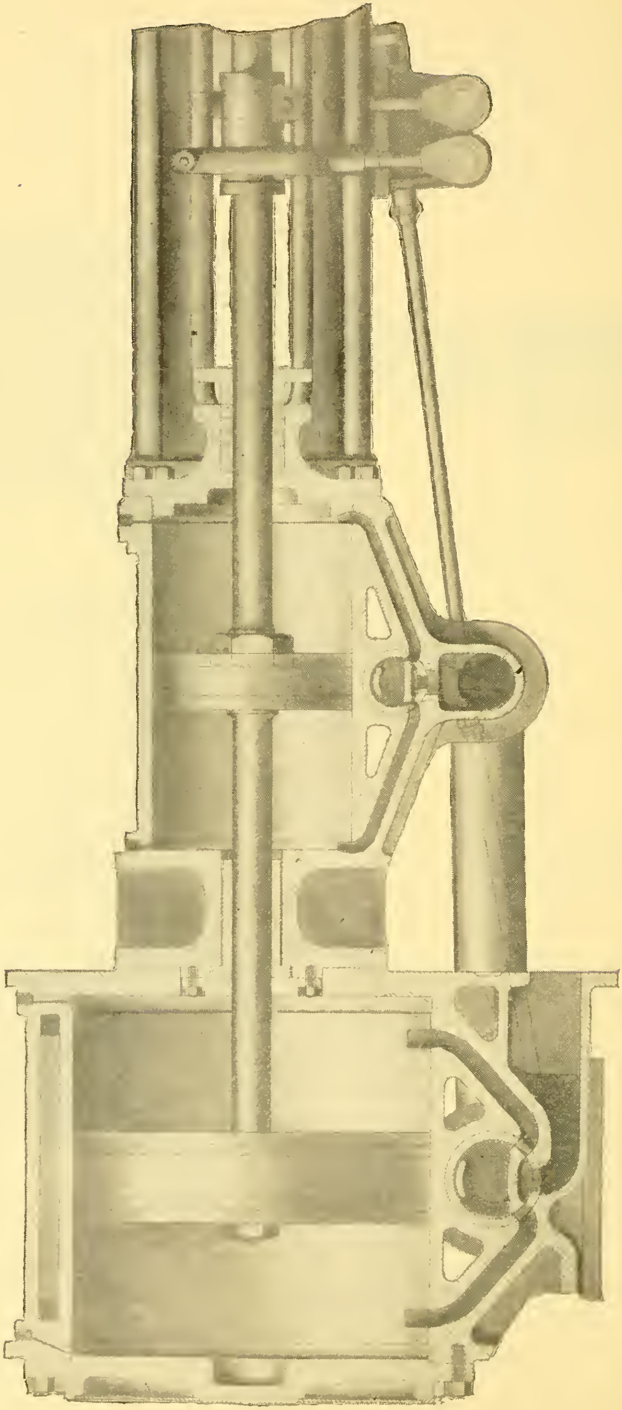


Fig. 7.

pumping against a pressure of about 80 pounds. The trial developed a duty of 82,000,000 foot pounds per 100 pounds of coal fired, no deduction being made for ashes, etc., and from a report received from the engineer, we learn that the average yearly duty on coal, including banking and heating and when running only an average of about four hours a day, is 73,000,000 foot pounds.

In the majority of cases the running engineers fail to keep accurate records of their engines, but it will be found that, in most every case, engines of this type are steadily maintaining the duties claimed for them.

Taking up the question of first cost for the purpose of comparison, let us take a compound condensing and triple expansion engine of say 2,000,000 gallons capacity in 24 hours working under 80 pounds head, all conditions being identical in both cases. The compound could be furnished complete with foundations and all piping within the engine house for about $3,600, the triple expansion with all the above for about $5,400. Estimating coal at $4 per ton, and the duty of the compound on the basis of an evaporation of 10 to 1, to be 55,000,000 and the triple 80,000,000, which we think is a conservative estimate and is giving the compound the benefit of the doubt, if any.

To run the compound for 24 hours would then consume 5,616 pounds of coal at a cost of about $11.20. The triple for the same length of time would consume 3,900 pounds of coal at a cost of $7.80, thus effecting a saving of $3.40 per day or $1,241 per year.

This saving is equivalent to 23 per cent. of the first cost of the engine, and deducting from it 6 per cent. on the original cost, or $324, for depreciation and ordinary wear, and 5 per cent., or $270, for interest, there remains a balance of $647 to the credit of the triple expansion engine.

If the net saving were capitalized at the rate of 5 per cent. per annum, it would represent $13,000, an amount amply justifying the first cost of the triple expansion engine.

Should the estimates be increased by the addition of boilers, it is evident that the triple expansion engine will require a boiler of smaller commercial rating than the compound condensing and at a correspondingly lower price.

The cost of operating the triple expansion engine, including

wages of engineer and fireman, oil and waste and the item of repairs, is no more than for a compound engine of the same capacity, and the comparison will be favorably maintained under different heads and capacities.

The above calculation of saving of the high class engine is based on the assumption that the plant is operated for 24 hours a day. When this is not the case the estimate must be modified to suit the existing conditions.

These are facts drawn from actual experience which are not generally appreciated and which it is my privilege to bring to your attention, in the hopes that, as your need of additional pumping machinery becomes apparent, you will call for the simplest and most economical type of engine, especially for moderate sized plants.

SUMMARY.

Comparison of Compound and Triple Expansion Pumping Engines.

Capacity 2,000,000 gallons per diem. Head 80 lbs. Coal $4 per net ton.

	Compound.	Triple Expansion.
Cost	$3,600	$5,400
Duty (foot pounds)	55,000,000	80,000,000
H. P.	65	65
Coal per H. P.	3.6 lbs.	2.5 lbs.
Coal per day	5,616 lbs.	3,900 lbs.
Coal at $4 per ton	$11.20	$7.80
Coal per year	$4,088	$2,847
Saving per day		$3.40
Saving per year		$1,241
Per cent of cost	23 %	
Deduct for depreciation 6 % and 5 % for interest		$594
Balance in favor of triple expansion engine		$647

Equivalent to 11.8 % on original cost.

Capitalized at 5 % equivalent to $13,000.

THE LATEST DESIGNS IN WORTHINGTON PUMPING MACHINERY, COMPARING THEM WITH THE PRACTICE OF TWENTY YEARS AGO.

BY CHAS. C. WORTHINGTON.

[*Presented Dec. 14, 1898.*]

At the beginning of the period mentioned in the title of this paper, the Worthington water works pumping engine had been reduced for some years to practically standard lines of construction. It consisted of high and low pressure cylinders placed tandem, two on each side of the engine, which were provided with plain slide valves generally fitted with some form of balancing device. In this form it had been applied to upwards of 90 pumping stations, and had become very generally distributed throughout the United States. (Plate No. 1.) It disputed the field with a variety of crank and fly-wheel engines that were credited with a much higher duty performance, but which were of greater cost.

To the claims that have always been made for the Worthington engine of reliability, simplicity and uniformity of propulsion, it was necessary at this time to make the added one that these competitive engines could not save enough coal over that required by the Worthington to justify their extra cost. This commercial side of the competition brought out in the old days many discussions more or less heated, between the advocates of the two types of machines. Nor has the subject of the proper annual charge for investments in pumping machinery been by any means exhausted since. It is rather strange that this calculation, that involves the most ordinary principles of investment, is so little understood by many writers on the general subject of water works installations. It is not unusual to see the extra purchase price of an engine charged with only 5 per cent. interest in making comparisons between costs. In these days, when engineers are taking very practical and business-like views of all matters pertaining to the economic administration of

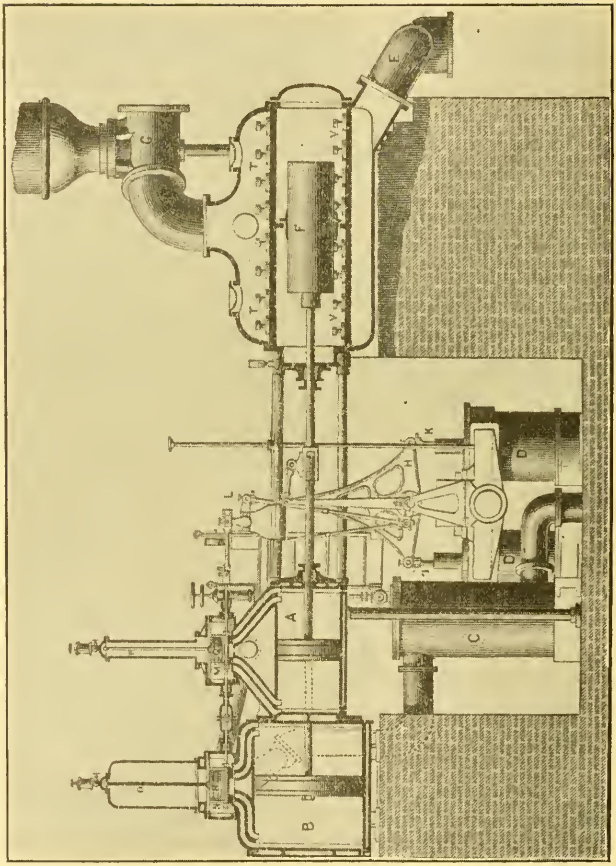


Plate No. 1.

Sectional View of Standard Form of Worthington Engine in 1880.

their work, and when they are relied upon to counsel the investor as to the ultimate returns to be gained by a given expenditure, it is of the utmost importance that this question should be definitely settled and the same rule of calculation adopted by all alike. If a proper percentage were charged against some of the recent investments that have been made for high class pumping machinery, it would often be found that those engines, which take first rank in economy of fuel, were really the most costly that the city could purchase.

It is plain to see that in arriving at this proper charge, the following items should be considered:

First. Simple interest upon the investment. This, for the purpose of discussion, may be taken at 3 per cent.

Second. A fair percentage, to cover the items of repairs and maintenance. No experienced engine builder would agree to bear the expense of the up-keep of his engine for less than an annual charge of 3 per cent.

Third. An additional percentage, to form a sinking fund, which shall equal the original expenditure when the engine becomes worn out, or is replaced by a more up-to-date machine.

In view of the advance during the last few years in the art of engine construction, and the tendency of the times towards radical changes in old methods, it is safe to predict that the majority of the best engines built today will be replaced, as obsolete and wasteful, twenty years from now. This is a fair estimate of the lifetime of many of our modern engines. But even extending this period to twenty-five years, the sinking fund imposes an annual charge of 4 per cent. This, then, taxes our original expenditure with an interest rate of 11 per cent. Taking this at 10, to escape all cavil, it still remains a sum much higher than is generally selected by writers on the subject.

In the early discussions to which we have referred, not only was this interest account of vital importance to the claims of the Worthington engine, but also the question of what was the actual amount of coal an engine giving a higher test duty could practically save. Often the comparison was distorted by estimating that the calculated saving per horse power per hour would be secured for the 24 hours of the day, 365 days in the year. You gentlemen, who

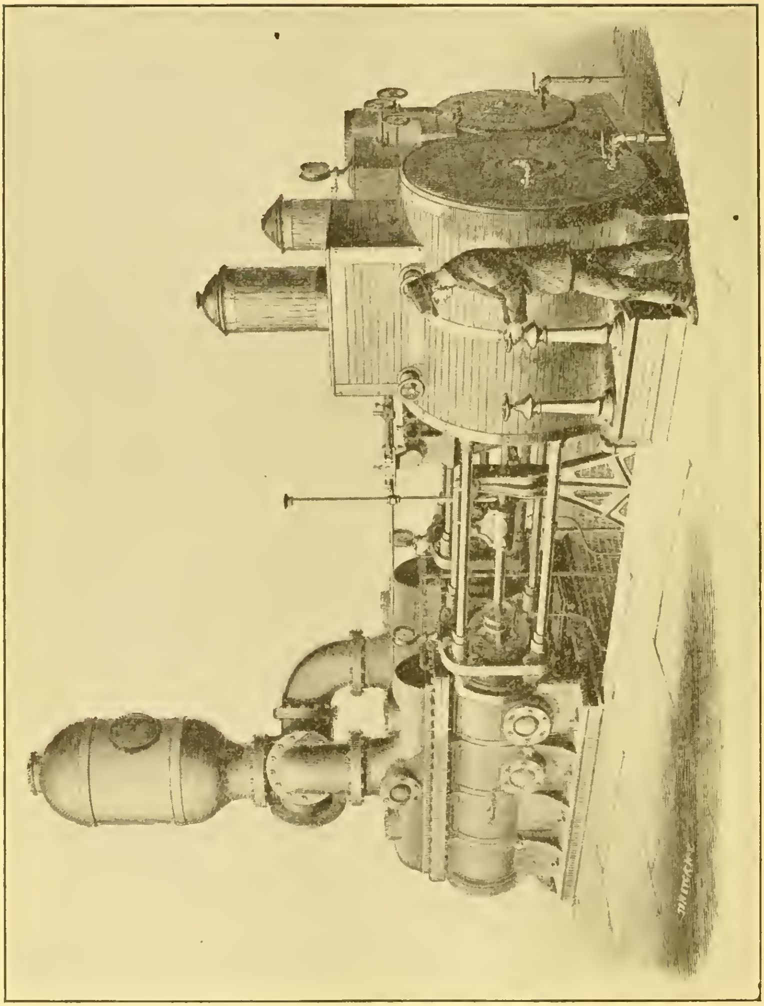


Plate No. 2.
WORTHINGTON TANK ENGINE, 1885.

have personal experience in the running of pumping stations, appreciate that few pumping engines are ever called upon to work continuously during the whole year. In making the comparison between engines of different grades, it is as true today as it was twenty years ago, that the number of hours in which the engines are to be run should be taken into account, as they represent the only time in which the estimated saving of the higher class engine can be secured.

This commercial argument was for a number of years strongly on the side of the Worthington engine, because the difference between its cost and that of the engines with which it was in competition was very considerable. But as less expensive designs were adopted, and as the duties were gradually improved, this difference became less marked, and the calculation less favorable. Finally, the builders of the Worthington engine were forced to the conclusion that something would have to be done to raise its economy, or it would be driven out of the field of high class water works stations altogether. It was also sought to decrease its cost. Experiments were conducted with what was called the tank engine (Plate No. 2), whose steam end consisted of two cylinders, placed side by side, instead of four of the older type. It was thought that by decreasing the number of cylinders the cost would be reduced. It was found, however, that the practical difference was inconsiderable, while the performance of the engine itself was less satisfactory. The ratio between the high and low cylinders of the 4-cylinder type was usually fixed at about $3\frac{3}{10}$ to 1, while in the tank pattern it was made from $7\frac{1}{2}$ to 8 to 1. In point of economy, there was little difference between the two types, but the tank engine was more difficult to adjust. It was found that the balance of the two sides of the engine was thrown out somewhat by the variations in steam or water pressure, commonly met with in service. In view of the recent able and instructive presentation by Mr. Rockwood, of the theory of his engine, the performance of this one, with its high ratios of cylinders, takes on a reflected interest.

During these experiments with the tank type, it was suggested to place two complete pumps side by side, and exhaust the one into the other, in the way that has since been done in a feed apparatus for marine boilers, recently made the subject of a paper before the

American Society of Mechanical Engineers. The action of the two machines, and the effect upon the water column, were so irregular, however, that it was deemed an impracticable method of securing the benefit of compound cylinders in engines of large size. The speed at which one engine ran with respect to the other was found to vary with the fluctuations of the water pressure.

At the time of which we are writing, the best duty to be secured by either the tank or 4-cylinder type of the Worthington engine might be placed at 29 pounds per horse power. To raise this, then, became the object sought for by its builders. The engine had gained for itself an enviable position; its great simplicity and adaptability to all kinds of service were universally admitted; and it had been reproduced on the same lines of construction more frequently than any other pumping engine of that day or now. It may be said to have been the first pumping engine whose design had been reduced to standard patterns, and its low cost, the cheapness of its foundations and of the building required to accommodate it, gave it a strong hold on the less pretentious stations of the country, from which even now, with all the competition of high duty types, it is difficult to dislodge it.

Little could be expected in the way of improved efficiency by any change in the arrangement or ratios of the cylinders themselves. The necessity of maintaining a uniform speed of propulsion throughout the length of the stroke prevented any greater proportion of cylinders being used than about 4 to 1, and yet it was realized that unless the number of expansions could be increased, there was little chance of any marked improvement in the steam consumption of the engine. It was at times feared that perhaps the duplex engine had reached its ultimate results, and that it was destined to be relegated to a position second-rate among the high class water works engines of the world. Many of its warmest adherents suggested that the fly-wheel offered the only chance for improvement, and the Holly-Gaskill engine, which at that time was making inroads into the field, and which embodied, apart from its fly-wheel, many features of construction similar to those of the Worthington engine, was pointed at as a significant warning.

Being unwilling to sacrifice the traditions of the business or to abandon the admitted advantages in handling water which the

duplex motion possessed over any motion derived from the action of a crank, we began a search for some equivalent to the fly-wheel. Devices embodying the principle of tumble-bobs where a weight would be lifted at the first part of the stroke and in descending would give off its reserve power at the latter part, as well as numerous others, embodying the principle of momentum, were investigated, but all were considered impracticable from one cause or another, but in the main because they added the danger of greatly increased weight of moving parts to the inherent difficulty of stopping the engine at the end of the stroke. What was necessary was a power that, while sufficient in itself to represent the work of a fly-wheel, of any size whatever, would leave the engine practically as free to start and stop as if it were not exerted. Such an attachment was finally found, and converted the engine into what is now known as the Worthington High Duty. This attachment has been so often described and so many of the engines have been built, that a detailed description of it here is not necessary. Suffice it to say in brief that the principle embodied in the compensating cylinders is capable of producing the same effect upon the steam diagrams of the engine as a fly-wheel could produce. In other words, there is nothing inherent in their application which prevents the steam being utilized in the engine to the highest point of economy at present obtainable in engineering practice.

At the start, some difficulties in construction naturally were met with. The experiment was along unknown lines. No books had been written on the subject, no experience had been gained which could serve as an aid in carrying out the improvement. This, we think, should not be lost sight of in discussing today the relative theoretical merits of the direct acting and the fly-wheel engine. While the one embodies the accumulated experience and effort of over a century of the world's best engineering talent, and has been brought to its present state through the crucible of many mistakes and failures, all of which have served as guides and danger signals to the present constructors, the other stands as the result of the unaided effort of one company to produce an engine that had to be a success from the start, from an engineering standpoint not only, but from a commercial one as well. When the time comes for the minds of engineers at large to be directed towards the principles in-

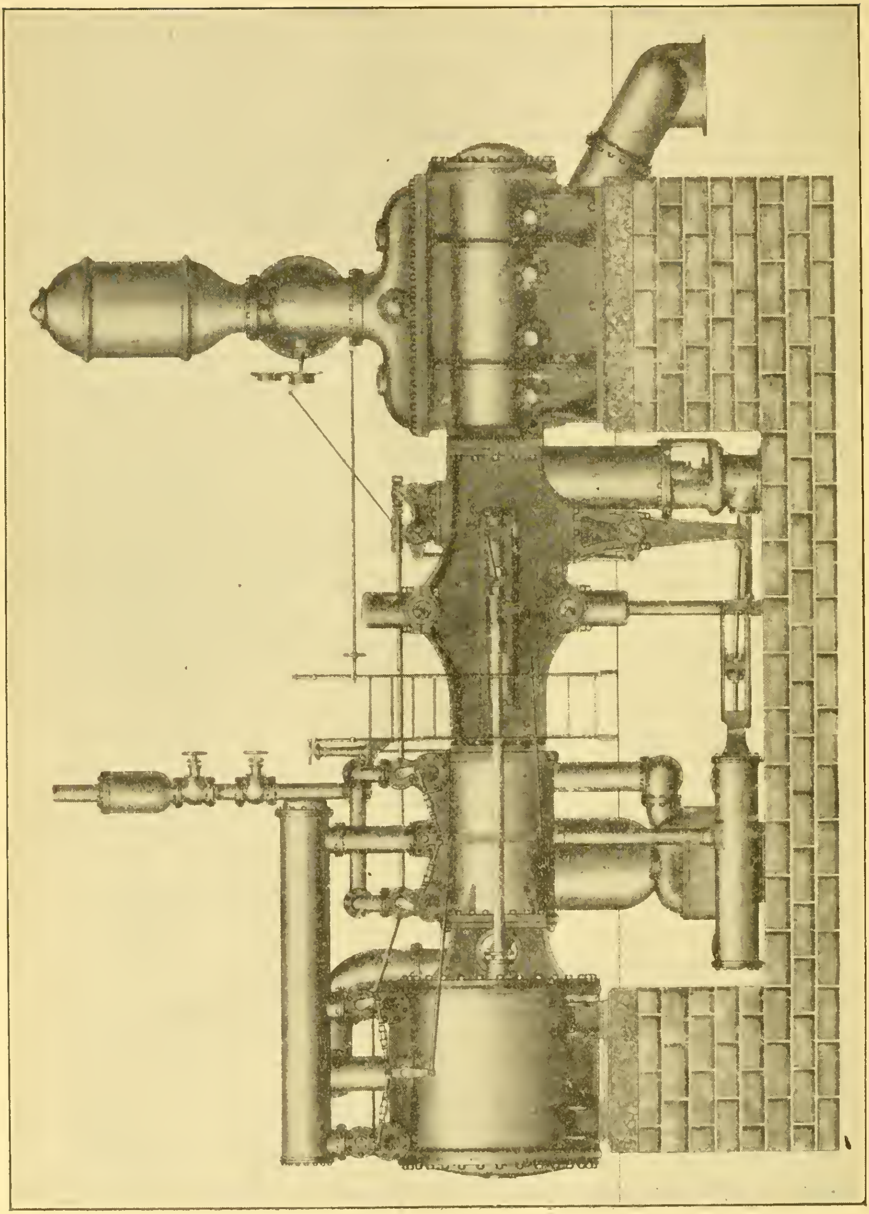


Plate No. 3.
Worthington Compound Condensing High Duty Pumping Engine, 1895.

volved in the Worthington High Duty Engine, we believe that those principles will be found enduring and that in their hands, when ours perhaps have "knocked off" work, the future history of the engine will be far brighter and more prominent than that of its older rival.

On the first engines to which this attachment was connected, as few changes in the former construction of the machine were made as circumstances permitted. Practically the only addition to the old engine, other than the attachment itself, was the cut-off valves. The old form of slide valve was adhered to. The compound condensing engine, thus fitted with compensators, at once achieved a duty of about 19 pounds per horse power. From that time on, such improvements in its details as have been made have enabled the same engine to show 16 pounds. The changes in the steam cylinders related principally to the location of the valves. It was found that the slide valve could not be relied upon to be tight under the new conditions of higher steam and greater expansion and that its steam ports contained more clearance space than was desirable. This led to a change from the slide to the semi-rotative type of valve. These, in the first engines, were located at the top of the cylinder, one at each end, and performed the function of both inlet and exhaust valves, the cut-off valves being separate ones and placed directly over them. (Plate No. 3.) While this reduced the clearance of the engines, simplified its valve motion and improved its economy, it was thought that still better results could be secured if the inlet valves could be made to perform the function of cut-off as well, and could be separated from the exhaust ones with an arrangement of valve chests, such as are common to the Corliss engine. This required, however, a valve motion of special design, as the ordinary trip motion of the Corliss gear is inapplicable to an engine of the direct acting type. Within the past two years the valve motion illustrated in the accompanying Plate No. 4, has been adopted, and in its principle of operation is believed to be unique. As will be seen, the admission valves, which are also the cut-off ones, are located at the top of the cylinder and the exhaust valves at the bottom. These latter are operated by direct connection with the disc, which disc is vibrated back and forth by link connections to the rockshaft operated by the steam cylinders on the opposite side. When this disc vibrates, that which may be described as the

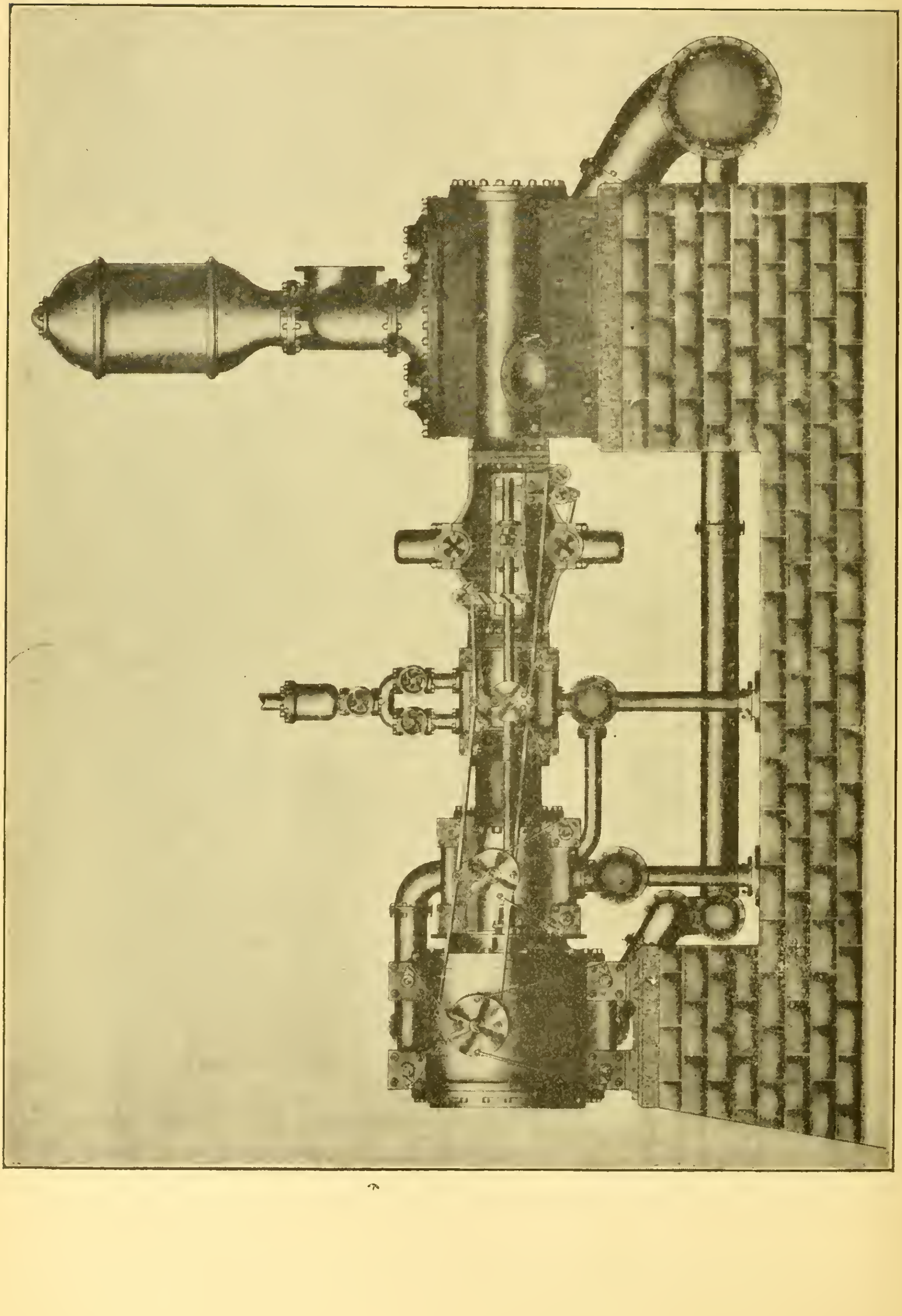


Plate No. 4.

Worthington Triple Expansion High Duty Pumping Engine, 1898.

"four-armed crank," which is pivoted to the disc, is made to move with it in such a way as to open the valve on one end of the cylinder for the admission of the steam. While making this movement it is fulcrumed on the point of connection with the link that is driven by its own engine. When steam is thus admitted, and the engine starts on its stroke, the disc being then stationary, the four-armed crank pivots on the point of connection with the disc, and is moved by the other link in a reverse direction, thus cutting off the steam. Through the angles of the cranks on the cut-off valves, this cut-off motion is remarkably rapid, and produces a steam diagram that is all that can be desired. Any point of cut-off can be secured by changing the location in the four-armed crank of the sliding block which carries the valve link. It will be seen from this that there is no trip or lost motion to this gear. It is absolutely noiseless in its operation, and as the work which it has to perform is done through long leverages, the wear on the pins and bearings is reduced to a minimum.

Following the demand for still higher duties, Triple Expansion Worthington Engines have been introduced during the last few years. These, particularly when used in connection with the higher steam pressures, that are at present met with, can be relied upon to secure a duty of 14 pounds per horse power. Usually, the steam is cut off in all three of the cylinders, so as to do away with any "drop," or expansion, without work. We are inclined to agree with Mr. Rockwood, that the precaution which we, in common with some other engine builders, take to prevent this drop, may be unnecessary. In the absence of any conclusive experiments in this direction, we have simply followed the general practice on theoretical lines. In this connection it is to be hoped that before long an engine for experimental purposes will be built, through the efforts, perhaps, of an Association like your own, of such size and power as to make any results reached in experimenting with it conclusive, and by which questions like this one, that are constantly being asked, could be authoritatively answered. The one that Mr. Rockwood has raised is of enough importance in itself to justify the expense of such an undertaking. Coupled with this could be the equally important one of the effect of high speed on the economy of an engine. While it is the custom to assert that there

is a saving in fuel to be secured by an immoderately high speed engine over a moderately slow one, the fact is that there is nothing positive known about it at all. A statement that a high speed engine is, *per se*, more economical than a slow speed one, is pure guess work from any data that we have today. No one can speak with assurance, either, as to the economy of jackets; no one knows what the exact effect is of superheated steam, nor the temperature at which this effect can best be utilized.

These and perhaps other equally important questions are constantly arising, many of which could be set at rest by a series of trials conducted by a board of experts on an experimental engine of the kind herein suggested. The time has come, we think, when a concerted effort in this direction should be made by the societies of the country, among which none could be more interested in the results than yours.

Perhaps the latest departure from the old method of construction of the Worthington, has grown out of the necessity of meeting the demand for vertical engines. Numerous Worthington engines of this type, both of the compound and triple expansion class, have been erected, an example of one being shown in Plate No. 5. In general principles it does not vary from the horizontal pattern, but the necessity of taking care of the weight of the moving parts of the engine, when in a vertical position, requires the addition of a balancing device. In its usual form this consists of a plunger of such area that, when acted upon by air pressure enclosed in a tank, it will exert an upward lifting force exactly equal to the superimposed weight of the rods and pistons. This tank is of such volume as not to materially change its pressure under the alternate compression and withdrawal of the air under the action of the plunger. As the tank is tight, and the leakages around the plunger are protected by water, no practical loss of this air pressure is sustained.

Since the date of the invention of the high duty attachment, 1886, well within the period we are considering, there have been built for water works stations more than 1,400 Worthington engines. About 15 per cent. of these in number, and by far a larger proportion measured by horse power, have been of the high duty type. This record, which would indicate that more Worthington engines

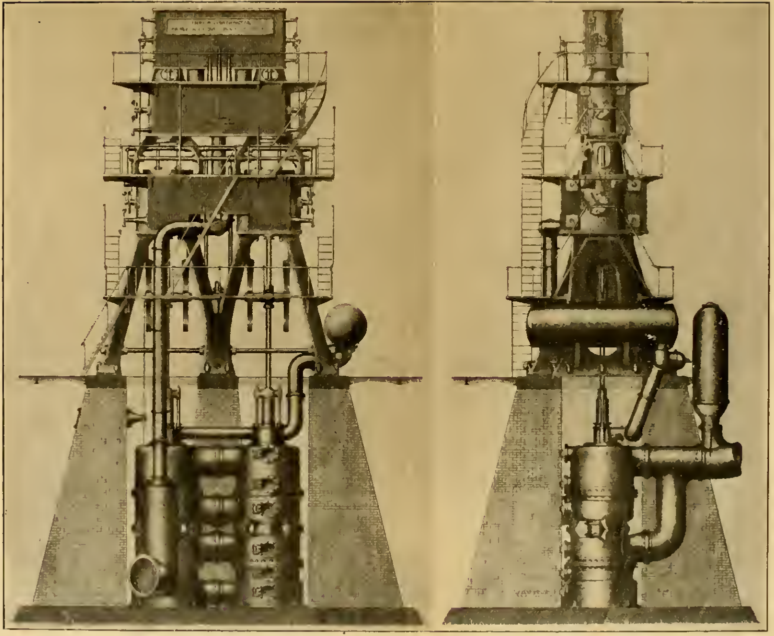


Plate No. 5.

Worthington Triple Expansion Vertical High Duty Pumping Engine, 1898.

have been constructed during that period than of all other types of pumping engines combined, could never have been approached were it not for the discovery of the means that we have briefly described, whereby the economic efficiency of the duplex engine was more than doubled without eliminating those peculiar merits upon which its old reputation was based. Perhaps never before in the history of engineering has there been an instance where so important and well known a machine, built on approved and standard lines, has been so markedly raised in efficiency in so short a time, and with so few changes in its principles of operation and details of construction.

PROCEEDINGS.

QUARTERLY MEETING.

Young's Hotel,

Boston, December, 14, 1898.

President Forbes was in the chair, and the following members and guests were present:

ACTIVE MEMBERS.

Charles H. Baldwin, Lewis M. Bancroft, George E. Batchelder, Joseph E. Beals, James F. Bigelow, Dexter Brackett, E. C. Brooks, George F. Chace, Charles E. Chandler, Benjamin R. Chapman, John C. Chase, William F. Codd, Freeman C. Coffin, R. C. P. Coggeshall, Byron I. Cook, Henry A. Cook, Francis W. Dean, Charles R. Felton, Richard J. Flinn, F. F. Forbes, Frank Baldwin French, Frank L. Fuller, Julius C. Gilbert, D. H. Gilderson, Albert S. Glover, W. J. Goldthwait, Frederick W. Gow. E. H. Gowing, John C. Haskell, Louis E. Hawes, T. G. Hazard, Jr., Horace G. Holden, Willard Kent, Frank C. Kimball, George A. Kimball, James W. Locke, Arthur D. Marble, A. E. Martin, Frank E. Merrill, Leonard Metcalf, Thomas Naylor, Frank L. Northrop, W. W. Robertson, Henry W. Rogers, W. J. Sando, John E. Smith, J. Waldo Smith, George A. Stacy, Frederic P. Stearns, Lucian A. Taylor, Robert J. Thomas, William H. Thomas, D. N. Tower, William W. Wade, J. Alfred Welch, John C. Whitney, George E. Winslow.

ASSOCIATE MEMBERS.

The Edward P. Allis Co., by Irving W. Reynolds and Arthur West.
The George F. Blake Manufacturing Company, by George J. Foran.
Coffin Valve Company, by J. Alfred Welch.
Crosby Steam Gauge and Valve Company, by Robert Pirie.
Deane Steam Pump Company, by C. L. Newcomb.
Hersey Manufacturing Company, by James A. Tilden.
Ludlow Valve Manufacturing Company, by H. F. Gould.
McNeal Pipe and Foundry Company, by J. M. Holmes.
Mueller Manufacturing Company, by M. G. Millikin.

National Meter Company, by Mr. Lufkin.
Neptune Meter Company, by Mr. H. H. Kinsey.
Perrin, Seamans & Company, by H. L. Bond.
Rensselaer Manufacturing Company, by F. S. Bates.
Builders' Iron Foundry, by T. C. Clifford.
A. P. Smith Manufacturing Company, by W. H. Van Winkle.
Union Water Meter Company, by F. L. Northrop.

HONORARY MEMBERS.

G. H. Partridge of the "Engineering Record."

GUESTS.

A. H Keene, C. E Riley, W. B. Webber, A. H. French, H. T. Gibbs, J. G. Moore, Mr. Rockwood, Julian P. Wood, Harry L. Thomas.

The following named persons were elected members by ballot cast by the Secretary:

RESIDENT ACTIVE.

Frank Livermore Pierce, of Newton, Special Inspector with the Factory Mutual Fire Insurance Company.

Harry L. Thomas, Assistant Superintendent, Hingham Water Company, Hingham, Mass.

John N. Ferguson, Boston, with Metropolitan Water Works.

Henry R. Johnson, Water Commissioner, Reading, Mass.

George J. Foran, with the George F. Blake Manufacturing Company.

The President read a short paper on "Pumping Engines," which served as an introduction to the other papers, all of which related to the same general subject.

George H. Barrus, M. E., of Boston, contributed a paper entitled, "Possibilities of Economy in Pumping Engines, as Based on the Latest Accomplishments." The paper was read by Mr. Gowing.

The next paper was prepared by Mr. Reynolds, a representative of the Edward P. Allis Company of Milwaukee, Wis., and was read by Mr. Chace. The subject was, "The Latest Designs in Pumping Machinery, Comparing Same with Practice of Twenty Years Ago."

Mr. Freeman C. Coffin, C. E., of Boston, read a paper entitled, "The Application of Oil and Gasoline Engines to Pumping Machinery."

John E. Smith, Superintendent, Andover, Mass., presented a

"Comparison Between Low and High Duty Pumping Engines on a Small Water Works Plant."

Mr. J. M. Betton, M. E., of Brooklyn, N. Y., was expected to have been present and to have read two papers, but he was prevented by business engagements from attending, and his papers were not read. The subjects were, "The Advantages of Triple Expansion Pumping Engines," and "The Latest Designs in Pumping Machinery, Comparing Same with Practice of Twenty Years Ago," the latter paper being prepared by him as the representative of Henry R. Worthington of Brooklyn.

There was oral discussion by Mr. F. W. Deane, Mr. Rockwood, Mr. Reynolds and Mr. Smith.

Adjourned.

48-in. Pipe Line—San Gabriel Power Co.

NEW ENGLAND WATER WORKS ASSOCIATION.

ORGANIZED 1882.

Vol. XIII. June, 1899. No. 4.

This Association, as a body, is not responsible for the statements or opinions of any of its members.

STAVE PIPE—ITS ECONOMIC DESIGN AND USE.

BY ARTHUR L. ADAMS, M. AM. SOC. C. E., LOS ANGELES, CAL.

[*Read Dec. 28, 1898.*]

This subject, in one or more of its aspects, has been briefly dwelt upon at various times by engineers when describing the construction of hydraulic works involving the use of pressure pipe of this type, but a full discussion of the various practical and economic problems involved in stave pipe design, and the determination of its real place among standard types of pressure pipes, have yet to appear.

The great dissimilarity in practice indicates either a very general unfamiliarity with the principles involved, or much difference of opinion regarding their practical application. That there is need for a better understanding of these principles, and of the correct limitations of the pipe's successful and economic usefulness, is apparent from the not infrequent partial disasters that have attended its attempted construction. That it has today a place among standard types of construction is apparent from the remarkable degree of favor accorded it by every one who has used it intelligently. The author firmly believes that the use of this pipe, now chiefly confined to the West, is destined to receive greatly extended recognition among engineers everywhere.

These considerations seem sufficient to warrant this presentation, which it is hoped may serve as a starting point for the evolution of clearer and more generally accepted ideas relative, not alone to the details of stave pipe design, but to the broader question of the com-

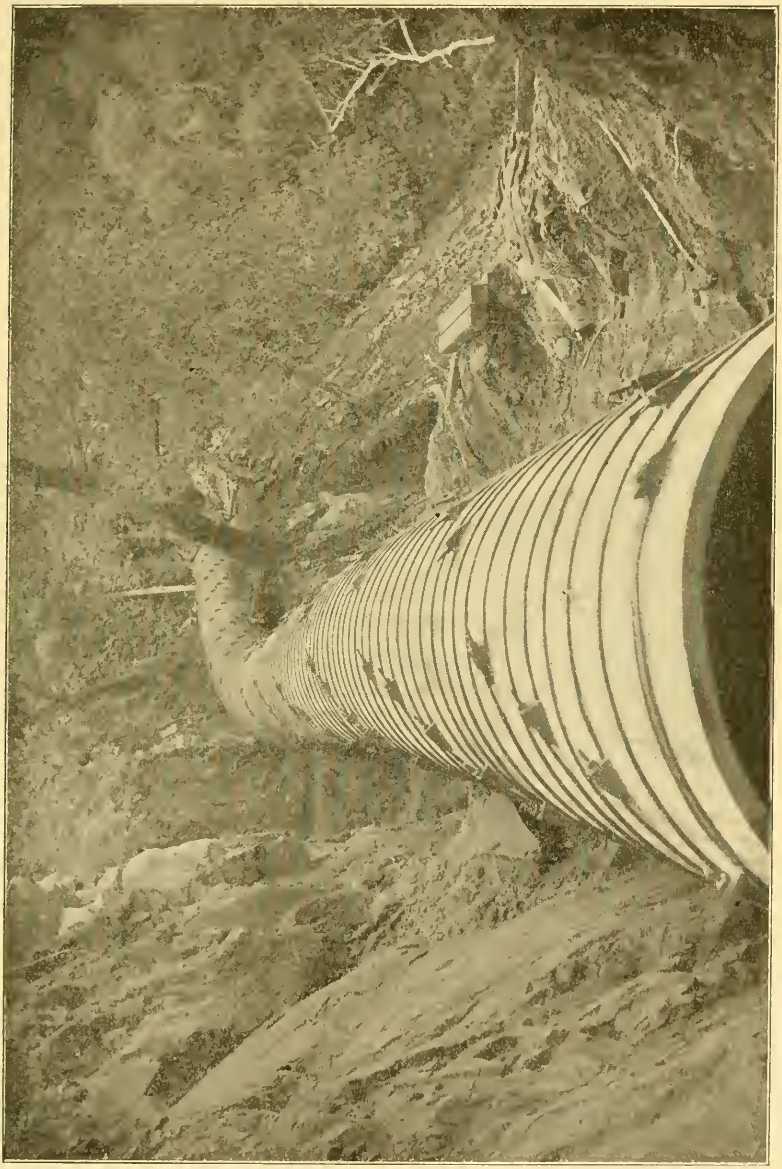
parative economies of different classes of pressure pipes—a question which recent important experiments and accumulating experiences have done much to reopen to argument.

In treating the subject, the author proposes to discuss the essential considerations in stave pipe design, and some of the practical and theoretical limitations imposed. Supplemental thereto a study will be made of several existing pipe lines, with reference to the details and factors used and the attendant results; and, finally, having outlined a simple and rational method for making a safe and economic design, a comparison will be made between the leading types of large pressure pipes, with reference to their relative first cost, durability, carrying capacity, and minor considerations, from which the author will seek to determine the rightful place of stave pipe in economic construction.

GENERAL TYPE CONSIDERED.

At first stave pipe was principally used for pen stocks in the development of water power, and was built in tapered sections which were put together after the manner of stove pipe. Apparently the first instance of its use as a continuous tube was the 6-foot penstock constructed at Manchester, N. H., in 1874, by J. T. Fanning, M. Am. Soc. C. E., and which is still doing service. Bands of round section were suggested by certain letters patent as early as 1880, and were first put into extensive use at Denver, Colo., in 1883. The particular type referred to in this paper is that which has been thus evolved, i. e., a pipe which is built continuously in the trench of staves of variable length, having radial edges and concentric faces, and which are held together by metal bands usually circular in section and spaced in accordance with the demands of the strains imposed.

In the design of a wood-stave pipe, the following essential points require consideration: The staves must be thin enough to secure complete saturation and to deflect readily to the degree of curvature employed, and they must be thick enough to prevent undesirable percolations through them. The bands must be of such size that, when spaced to secure the desired factor of safety against rupture, there will at the same time be no sensible flexure in the staves and no destructive crushing of the fiber beneath the bands. While fulfilling these conditions, the proportion between the thickness of the



48-IN. PIPE LINE—SAN GABRIEL POWER CO.

staves and the strength and spacing of the bands must be such that the swelling of the wood will not produce injurious strains upon what might otherwise be a properly proportioned band.

These are the primary considerations, generally stated, which should govern all design, and the author believes it will be profitable to consider them in detail, to point out some of the limitations of each, the effect of certain practical considerations, and to reduce the whole to a form easy of application. To do this intelligently a clear conception of the nature and source of the probable strains set up in the construction and operation of the pipe should first be secured.

SOURCES OF STRAIN.

The tensile strains resisted by the bands are from three sources:

(1) The initial strain, caused by cinching during construction.

(2) The pressure of the water within the pipe.

(3) The swelling of the staves.

The strains resisted by the staves are from the following sources:

(1) The compressive strain of the bands.

(2) The compressive strain upon the edges of adjoining staves.

(3) The pressure of the water producing flexure of the staves between adjacent bands.

The fact that most of these strains, in their amount and importance, are more or less inter-dependent makes any separate determination of the values of each impossible without coincidently determining the nature of their mutual relation under some variety of conditions.

CINCHING STRAIN.

It is evident that to secure a pipe that shall be tight, or practically so, when first filled, the initial cinching strain must be sufficient in extent to produce:

(1) A degree of compression per square inch between the staves in excess of the water pressure.

(2) A uniform contact between the band and all the staves; and, if the band be of a curved section, a sufficient indentation of the wood to afford the band a bearing contact sufficient in area to resist, without further immediate indentation, the water pressure incident to the filling of the pipe.

If these conditions are not complied with, it is evident that leakage must ensue until the necessary compression between the

staves, and the requisite area of contact between the bands and the staves are supplied by the swelling of staves. Whether this will be accomplished or not will depend chiefly upon the degree of seasoning of the staves. That the question of seasoning, in securing tight pipe, so long as the staves are uniform, is relatively unimportant, with proper cinching, seems to follow logically, though the practical difficulties incident to the handling and shipping of the heavier green timber, and the prevention of unequal shrinkage before getting the staves into the pipe, usually make the at least partially seasoned timber the cheaper. It is apparent that back-cinching, to a degree productive of greater compressive strain than is essential to the foregoing requirements, is to that extent a needless addition to the cost of erection and to the band strain.

Owing to the friction between the band and the staves, and the compressive resistance of the wood, it is not found possible in practice to secure the necessary area of contact, under a band of curved section, by screwing up the nut at the end of the band, without inducing an objectionably high strain. To accomplish the result in a better way, the band is usually pounded vigorously at all points, simultaneously with the use of the wrench. Such a practice is highly commendable, and is, indeed, usually essential, as it tends to secure the proper degree of indentation with the least residual tensile strain in the band consistent with securing requisite compression between the staves.

Just what this cinching strain usually amounts to in practice depends upon the character of and the manner of doing the work, and is probably as variable as individual judgment. So far as it influences the success of the work, it is believed that the foregoing sufficiently elucidates the principles involved. In its effect upon the final working strain in the band, it will be shown later that a considerable variation in practice within reasonable limits will not seriously affect the final stresses, though, doubtless, much affecting the temporary strains resulting on first filling.

WATER PRESSURE STRAINS.

The strains induced in the bands by the pressure of the water within the pipe are susceptible of positive determination, and the methods of their solution are too well known to require any explanation herein.

STRAINS FROM SWELLING STAVES.

The additional strain caused by the swelling of the staves is less easily determined, and exists only within certain limitations of the first afore-mentioned source of strain.

With swelling timber, as with a steel spring, it may be assumed that its expanding power at a given stage of compression well within what may be called its elastic limit, is measured by the load necessary to produce that compression under like conditions. Hence its ultimate swelling power, at a given degree of compression, is the measure of its ultimate resisting power. It is also influenced by the hardness, direction of grain and such other conditions as affect the compressive strength of timber within its elastic limit when resisting forces applied across the grain.

If, then, the staves in a pipe be compressed laterally by the bands beyond the elastic limit of the saturated wood, there can be no swelling of the staves, and consequently no increased strain in the bands from this source. On the contrary, a farther compression of the fiber will result until an equilibrium is established between the compressive strain and the sustaining power of the wood; and if the sustaining power is below that requisite to resist the pressure of the water, leakage will of course result. If, on the other hand, the compression is less than the corresponding swelling power of the wood at the degree of seasoning and compression used, the timber will, by swelling when wet, develop an expanding power in some degree commensurate with the ratio of the volume of the uncompressed saturated stave to the same when compressed to the degree used, which expansion, of course, induces a correspondingly increased strain in the bands.

Thus there results the rather remarkable condition that if the bands, in resisting the water pressure, tax the staves beyond the limit of their permanent compressive strength, they, by yielding, release the excess of pressure, and leakage results; and if less is required of them than the most they are capable of giving, they force the band to take all the additional strain they are capable of exerting.

The amount of additional band strain thus induced is doubtless nearly proportional to the area of contact between the staves in the straight seams. The avoidance of unnecessary thickness of

Astoria Line—Showing Process of Erection.

staves, too long band spacing and the providing of such an area of contact between band and staves as shall give a necessary working compressive strain on the wood, not in excess of its permanent resisting strength, and only sufficiently below it to make certain of its not being exceeded by the water pressure ought, therefore, to commend themselves as prime essentials in avoiding unnecessary and perhaps injurious band strains.

The special advantage of a band of curved section, as contrasted with a flat band, now becomes apparent, since by the former a permanent compressive strain on the wood is provided sufficient to produce a decided indentation. The swelling of the staves, if any, and the accompanying increased compressive strains beneath the band are therefore followed by a farther yielding of the wood; and as the band strain increases, the area of contact with the band is increased by the farther indentation of the stave. With flat bands the unit compressive strain beneath them would almost invariably be so low that no indentation of the stave would result, and swelling strains to the full exerting power of the wood would be added to the band strains arising from other sources.

TEMPORARY AND PERMANENT STRAINS.

From the foregoing it is apparent that the strains resulting on first filling a pipe, or temporory strains, the necessary strains for permanently maintaining a tight pipe under pressure, and the permanent strains finally obtaining in the pipe, are three separate and usually very different quantities.

The permanent strains in a band are evidently the sum of those induced by final cinching, by water pressure and by the transverse swelling of the staves, subject only to the limitations imposed by the sustaining and swelling power of the wood when saturated.

The band strain necessary to maintain a tight pipe has already been shown to be that requisite to resist the water pressure and to maintain any excess of pressure between the staves needed to prevent seam leaks.

The temporary strain induced on first filling is the sum of the final cinching strain, the water pressure strain, and that arising from a swelling of the staves, subject only to the limitation of the immediate compressive resistance of the wood under the band while still dry, a limit scarcely reached in any proper construction.

STRAINS RESISTED BY STAVES.

In discussing the causes and effects of band strains, the character of the strains resisted by the staves have been made sufficiently plain. Their further influence upon proper design will be considered later.

EQUATIONS DEDUCED.

In the following equations for the various strains previously considered, the symbols used are as follows:

R = the internal radius of the pipe.

r = the radius of the band section.

t = the thickness of the stave, in inches.

f = the spacing of the bands between centers, in inches.

S = the tensile strain in the band, in pounds.

s = the safe tensile strain in the band, in pounds.

E = the permanent sustaining power of the staves, in pounds per lineal inch of band.

E' = the temporary sustaining power of the staves, in pounds per lineal inch of band.

E'' = the permanent swelling force of the wood, in pounds per square inch.

E''' = the temporary swelling power of the wood, in pounds per square inch.

P = the water pressure, in pounds per square inch.

e = the safe bearing power of the wood, in pounds per lineal inch of band.

X = the additional strain induced by band cinching in pounds.

The least band strain induced by water pressure = $P R f$.

The permanent band strain induced by swelling of staves = $f t E''$.

The least permanent strain in the bands of a tight pipe = $(X + P R f + f t E'')$, $< R E$. Assuming $X = \frac{3}{2} t f P$ and substituting, we have as the least permanent value of S for a tight pipe when $P < E''$.

$$S = \left(P f (R + \tfrac{3}{2} t) + E'' t f\right), < (R + t) E \ldots\ldots (1)$$

If $P > E''$, this becomes

$$S = \left((R + \tfrac{3}{2} t) P f\right), < (R + t) E \ldots\ldots\ldots (2)$$

which is the equation generally used for computing band strains for all pressures.

The least temporary band strain induced on first filling a tight pipe $= (X + P R f + E''' t f), < (R + t) E'$. Assuming as before, $X = \frac{3}{2} t f P$ and substituting, we have as the temporary value of S when $P < E'''$

$$S = \left(P f (R + \tfrac{3}{2} t) + E''' t f\right), < (R + t) E' \ldots\ldots\ldots (3)$$

If $P > E'''$, the equation becomes the same as (2).

From the foregoing the following equations, convenient for application, are deduced:

When $P < E''$:

$$f = \frac{s}{(R + \frac{3}{2} t) P + E'' t}, \text{ when } s < (R + t) e \text{ — (A)}$$

$$f = \frac{(R + t) e}{(R + \frac{3}{2} t) P + E'' t}, \text{ when } s > (R + t) e \text{ — (B)}$$

When $P > E''$

$$f = \frac{s}{(R + \frac{3}{2} t) P}, \text{ when } s < (R + t) e \text{ — (C)}$$

$$f = \frac{(R + t) e}{(R + \frac{3}{2} t) P}, \text{ when } s > (R + t) e \text{ — (D)}$$

Inasmuch as stave pipe has never been used under heads where the value of P is greater than E″, and since, as will subsequently be seen, it has not as great economic value under such heavy pressures as under lighter pressures, formulas (C) and (D) have no great practical value.

SUSTAINING AND SWELLING POWER OF STAVES.

In order to make use of the formulas, it is essential that proper values be determined for E, E′, E″, E‴ and e.

Since the sustaining power of wood depends upon the degree of its permissible compression within the limit of its ultimate crushing, it is necessary to assume some fixed amount of stave indentation as a basis for determining the probable values of E and E′. Now in the actual process of pipe construction, it has been frequently observed that an indentation equal to one-eighth of the radius of a round band, of such sizes as other considerations render suitable for use, may be produced in the stave without breaking the fiber,

while any considerable increase beyond this point has a destructive effect. This degree of indentation gives a bearing surface equal to half the diameter of the band, which may therefore be assumed as the greatest that can be safely obtained.

In considering contact between cylindrical bodies and the flat surfaces of saturated timber, the ordinary experimental data relating to flat surfaces having uniform contact with seasoned timber are scarcely applicable. The scarcity of experiments influencing the correct determination of these values is to be regretted, and it is hoped will yet be supplied.

So far as the author is aware, the only experiments available are those made by D. C. Henny, M. Am. Soc. C. E. A study of these experiments forecast some interesting conclusions regarding these values, and additional light is derived from a study of the strains prevailing in some existing pipe lines, as will be shown later. The experiments mentioned were made to determine the swelling power of Oregon "yellow fir." For convenience, the results are here reproduced:

TABLE NO. 1.

Date of Immersion.	Date of Observation.	Observed Strain in Bands, in Pounds.	Corresponding Strain per Square Inch Between Staves.	Corresponding Strain on Staves under Band per Lineal Inch of Band.	Corresponding Strain on Staves under Band per Square Inch of Contact.	Remarks.
		SECTION 1, No. 1.				
Feb. 27	Feb. 27	4,750	288	456	1,830	Initial strain before submerging.
	Mch. 1	3,400	206	328	1,310	
	" 4	2,950	179	284	1,140	
	" 7	2,750	167	265	1,060	
	" 9	2,525	153	243	970	
	" 12	2,525	153	243	970	
		SECTION 1, No. 2.				
	Mch. 12	100	7	10	38	Band was loosened to the strain indicated.
	" 18	1,500	91	145	580	
	" 21	1,500	91	145	580	
	" 26	1,550	94	150	600	

Section 1, No. 3.

	Mch. 26	500	30	48	190	Band again loosened to strain indicated.
	Apl. 1	1,000	61	97	390	
	" 4	1,050	64	101	400	
	" 8	1,100	67	106	420	
	" 11	1,200	73	116	460	
	" 15	1,225	74	118	470	

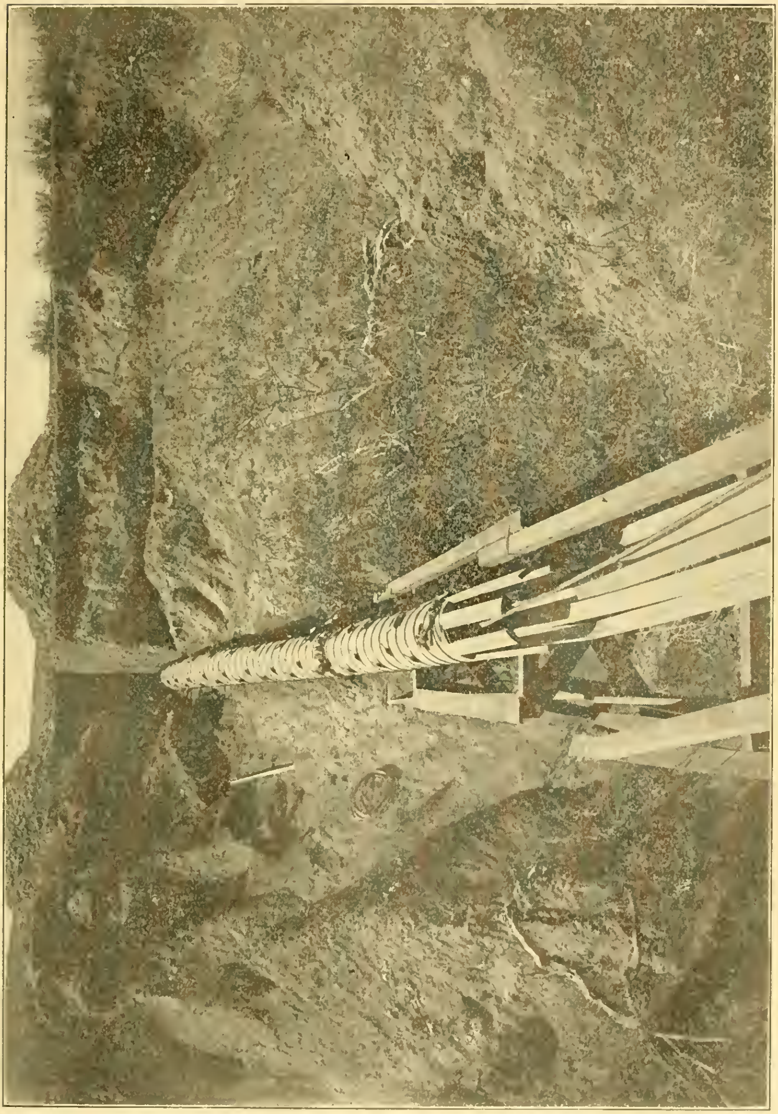
Section 2, No. 1.

Apl. 16	Apl. 16	450	33	43	170	Band was first drawn to tension of 5000 pounds and then released to the strain indicated.
	" 17	1,400	85	135	540	
	" 20	1,900	115	183	730	
	" 24	2,000	121	192	770	
	" 27	1,975	120	190	760	
	May 1	1,900	115	183	730	
	" 4	1,900	115	183	730	
	" 7	1,800	109	173	690	
	" 10	1,700	103	164	660	
	" 13	1,600	97	154	620	
	" 17	1,600	97	154	620	

In these experiments the bands were depressed into the staves until a bearing of half their diameter was secured.

In experiment No. 1, with Section 1, it will be noted that a very heavy initial tension was put upon the band, which the staves, after being immersed, could no longer withstand. The resulting compressive strain resisted by the staves under the bands accordingly fell from 456 pounds per lineal inch of band to 243 pounds, or 970 pounds per square inch of contact, at which point it became stationary, although, the staves being at this stage probably incompletely saturated, a longer immersion might have resulted in producing a slightly lower permanent resistance. The result is strongly indicative that this pressure of 970 pounds per square inch of contact is the utmost that in practice can be permanently resisted by the staves, while the subsequent experiments show that hard cinching and a full band bearing as here used are necessary to secure nearly so high a resistance. As will be noticed later, the correctness of this general deduction is practically substantiated by a study of some existing structures.

The resulting compression between the staves in this experiment is seen to be 153 pounds per square inch, a figure from which no conclusion can be drawn other than that the diminution in the band



14-in. Soldiers' Home Extension—West Los Angeles Water Co., During Construction.

strain must have been the result of yielding under the band rather than between the staves.

Experiments Nos. 2 and 3. with the same section, in which the band tension was successively released by means of the wrench, are evidently well calculated to determine the approximate swelling force exerted laterally by the staves. The staves having been compressed for a period of two weeks, to a degree under the bands well beyond the limit of the wood's elasticity, it is evident that a very slight lengthening of the band by unscrewing the nut would be immediately followed by the partial or entire release of the band strain. The amount of lengthening necessary for this result would doubtless be but a small fraction of the total, say 3 per cent. expansion by swelling, of which the kiln-dried timber would be capable if unresisted. The staves, not having been compressed laterally in the previous experiment to a degree in any way calculated to impair their swelling power, were then free to develop this power to the utmost within the limit of their ultimate bearing power under the bands, which the previous experiment has shown to be not less than 970 pounds per square inch of contact. On the first release of the band strain, No. 2, the staves developed a swelling power of 94 pounds per square inch. On the second release, they developed a power of 74 pounds per square inch, the power dininishing as might be expected as the wood gradually approached its full unrestrained proportions.

The experiment with Section 2 is a confirmation of the results derived from experiment 2 on Section 1. The pipe was but slightly cinched after the band had been brought to a proper bearing. The staves developed a swelling power of 97 pounds per square inch, a figure almost identical with that given by the previous experiment, while the resulting compressive strain under the band, 620 pounds per square inch, was not such under the prevailing conditions as to be likely to cause a degree of yield which would vitiate the result.

So far as they go, these experiments demonstrate: (1) That with a proper degree of compression, an ultimate permanent pressure of between 900 and 1,000 pounds per square inch of contact with the band may be resisted by the staves. This result may probably be conservatively assumed to obtain in the use of all bands of prevailing sizes, and of staves without regard to the character of the grain. (2) That the ultimate swelling power of the wood may be taken at

from 90 pounds to 100 pounds per square inch of stave contact in straight seams, a result which may be effected by the spacing of the bands, since a slight flexure in the stave would tend to release the strain instead of transmitting it to the bands. (3) That for water pressures exceeding say 94 pounds per square inch, and probably considerably less, hard cinching rather than the swelling of the wood must be relied upon to maintain a tight pipe. (4) That the yielding quality of the wood renders hard cinching not seriously objectionable in its effect upon final band strains with the usual factors of safety in the band and when working reasonably close to the limit of ultimate compressive resistance of the stave.

As it has been observed in practice that the difference in the compressive strength of Douglass fir and redwood is not very great when both are saturated, for the present purposes no distinction will be made between them.

One of the most important points to be determined from the foregoing is the maximum value for e which can be used with entire safety in designing a pressure pipe. It will be shown later that pressures as high as 1,100 pounds per square inch have been successfully used under favorable conditions, but the logical conclusions drawn from the previous discussion, as well as some results from actual experience given later, strongly indicate that such an assumption is insufficiently conservative for entirely safe construction. With thorough compression of the bands into the staves, well-seasoned lumber, skilled construction and entire immunity from water-hammer, it would seem that this value should not be taken much if any above 800 pounds per square inch, while if subject to any considerable fluctuations of pressure or to doubtful constructive skill, a much lower figure should be used.

In view of the foregoing the following values are assigned for use in the formulas previously given:

$E = 240$ pounds for $\frac{1}{4}$ inch bands, when the fiber is fully compressed (960 pounds per square inch).

$E' =$ say 500 pounds, in the absence of any experiment.

$E'' = 95$ pounds for 12-inch band spacing. Assumed at 100 pounds for all spacings.

$E''' = 120$ pounds for 12-inch spacing. Assumed at 125 pounds for all spacings.

$e =$ equivalent of 800 pounds per square inch of band contact or less.

DETERMINATION OF THE PROPER SIZE AND FORM OF BAND.

Before making use of any formula for the determination of proper band spacings, it is necessary to determine the size and form of section of the band that will most economically fulfill the requirements of any particular case in hand. The selection will be influenced by the following considerations: Bands less than $\frac{3}{8}$-inch in diameter are not suitable for use chiefly because of torsional weakness and difficulty of upsetting. An increase in the permissible value of e may be obtained without increase of metal section of band by using an oval form, which can be obtained at only a slight increase of cost above the rounds of similar weight. The price per pound for the bands is less for the heavier than the light sections. The use of upset rods or rolled threads is always economical, the latter being usually preferable because of the more perfect workmanship. The heavier the bands used, the fewer to be handled, the less the cost for both material and labor and the better the condition of the band section for resisting corrosion, though the added stiffness, increasing the difficulty of placing, will in the larger sizes partially offset these advantages.

Referring to the formulas for band spacing, it is seen that economy in the use of the steel requires the selection of a band of such sectional area that if possible $s < (R + t)\, e$, as otherwise it is necessary to use closer spacing—more steel than the pressure requires, in order to secure a sufficiently low value for e.

By writing $s = (R + t)\, e$, the greatest value of s for any given band section that can be used consistently with a desired value of e, may be determined; and by substituting for s and e their proper values corresponding to bands of various standard sizes, the limitations of the economic use of each may be ascertained, thus:

$$R + t = \frac{s}{e}$$

TABLE No. 2.—MINIMUM SIZES OF PIPE TO WHICH SPECIFIED BANDS ARE APPLICABLE WITHOUT EXCEEDING VALUES OF 650 LBS. AND 750 LBS. FOR e, AND A FACTOR OF 4 FOR THE BANDS.

Size of band.	s (=¼ ultimate strength.)	Band pressure per square inch.	e (Band pressure per lineal inch.)	Least external radius of pipe.	Band pressure per square inch.	e (Band pressure per lineal inch.)	Least external radius of pipe.
in.	lbs.	lbs.	lbs.	in.	lbs.	lbs.	in.
$\frac{3}{8}$	1,650	650	122	13.5	750	140	11.8
$\frac{7}{16}$	2,250	650	142	15.8	750	164	13.7
$\frac{1}{2}$	2,950	650	163	18.1	750	187	15.7
$\frac{9}{16}$	3,725	650	183	20.4	750	211	17.65
$\frac{5}{8}$	4,600	650	203	22 6	750	234	19.6
$\frac{3}{4}$	6,600	650	244	27.0	750	281	23.5

A factor greater than 4 must therefore be used in the steel in designing pipes of smaller diameter, if bands of round section are used, and the specified values of e are not exceeded. The band strains to be used are readily determined by the same formula as before indicated:

$$s = (R + t) e.$$

By the use of a band of oval section, a greater bearing surface is secured between the band and the staves with the same degree of indentation, thus permitting the use of less steel for given values of e, in designing pipes of smaller diameter. For this reason they have been already introduced and used by the Excelsior Wooden Pipe Company of San Francisco, on a number of pipe lines, though not with the economy that would now attend their use, as manufacturers have not until recently been able to quote the present figures which are but little in excess of the price for rounds. These conditions will doubtless lead to the general use of the oval section on small pipes, though any departure from the round sections has the disadvantage of exposing a greater relative surface to corrosive action.

TABLE NO. 3.—GREATEST BAND STRAINS CONSISTENT WITH SPECIFIED VALUES OF e FOR PIPES OF SMALL DIAMETER.

$\frac{3}{8}$-in. Round Bands.

Internal Diameter of Pipe.	External Radius of Pipe.	s (=Assumed Working Strains in Band.)	Factor of Safety in Band.	s (=Assumed Working Strain in Band.)	Factor of Safety in Band.
e = 122 lbs. = 650 per square inch.				e = 140 lbs. = 750 lbs. per square inch.	
12 ins.	7.1	866	7 6	994 lbs.	6 1
16 "	9.2	1,122	5.9	1,288 "	5 1
20 "	11.2	1,366	4.8	1.568 "	4.2
24 "	13.5	1,650	4.0		

The use of an oval section in the above cases would result in the saving of about 17 per cent. of the steel.

BAND SPACING.

If, in accordance with the foregoing, the proper band is determined for a pipe of given diameter, formulas A, B, C or D, may at once be applied to determine the proper spacing for any pressure and thickness of stave, the selection for any case being made by observing the relative values first of P and E, and then of s and $(R+t)e$ as indicated.

REQUISITE THICKNESS OF STAVES.

The staves must be thick enough to prevent percolation, to resist undue flexure with the band spacing adopted, to prevent cracking or crushing of quarter sawed staves during the process of cinching and to afford the rigidity necessary to support the weight of the pipe and backfilling without distortion. With these requirements met, the staves, for reasons already mentioned, should be as thin as possible.

Concerning percolation through the staves, in using Douglass fir under pressures in excess of about 80 feet, vertical and bastard grained staves only should be used if the staves are $1\frac{3}{8}$ inches in thickness. With this precaution, trouble will not arise from the splitting of quarter sawed staves, and this thickness will be found sufficient to resist percolation at any pressure under which

stave pipe is likely to be used. Redwood being of finer grain gives no trouble from percolation.

If the size of band for a pipe of any diameter, and the band spacings are determined in accordance with the foregoing principles, staves of the thicknesses generally used will always be safe against undue flexure if a maximum spacing of 12 inches is adopted. This is by no means an extravagant assumption, since this spacing will, in most cases, correspond to a very light water pressure; and if when designing a pipe of large diameter the band selected gives an unnecessarily large factor under light heads with this spacing, a smaller band can be substituted.

A practical consideration that has influenced very properly the thickness of staves, is the desirability of running them from timbers of commercial sizes. Thus by enabling the mill to dispose of rejected pieces, a lower price on the accepted staves is secured.

The practice of running staves from 2 inches x 6 inches, 2 inches x 8 inches and 3 inches x 8 inches stock nearly meets the economic requirements of pipes designed in accordance with the foregoing principles, which requirements will, however, be a little better conserved if $1\frac{1}{2}$ inches x 4 inches is used for the smallest diameters, and if the odd size $2\frac{1}{2}$ inches x 8 inches is used for certain sizes of pipes intermediate between those for which 2 inches x 6 inches and 3 inches x 8 inches are used.

A careful study of these and other requirements points to the following as being for general use the best balance between the various influences affecting the relation between pipe diameters and the size of stock for staves, the staves in each case being run as thick as the stock will permit.

Pipe Diameters.	Stock Sizes.
10 ins. to 14 ins.	$1\frac{1}{2}$ ins. x 4 ins.
16 " " 48 "	2 " x 6 "
50 " " 58 "	$2\frac{1}{2}$ " x 8 "
60 " " 72 "	3 " x 8 "

SUGGESTED STANDARD DESIGNS.

Assigning to e the conservative value of $\frac{650}{r}$, the author ventures to submit the following table of pipe diameters, with the corresponding stave thicknesses and character of bands, which, for the conditions of general use, he believes to be as closely in accord

with sound theory and economic practice as the present state of investigation and the constructive art will permit. The economy of these relative proportions is somewhat influenced by the locality of construction as affecting freight rates on the steel, but not to a serious extent. Should it be desired to use some other value of e than that designated, the needed modification can be made without difficulty.

TABLE NO. 4.—Economic Proportions for Pipe Designs.

Nominal Diameter.	Stock Sizes for Staves.	Thickness of Finished Staves.	Economic Sizes of Bands.	s (Permanent Band Strain.)	Factor Safety in Band.	e (Maximum Values $= \frac{650}{r}$.)
Inches.				Lbs .		Lbs.
10	$1\frac{1}{2}$ ins. x 4 ins.	$1\frac{1}{16}$ ins.	$\frac{5}{16}$ x $\frac{7}{16}$	1,255	5.26	207
12	$1\frac{1}{2}$ " x 4 "	$1\frac{1}{8}$ "	" "	1,475	4.47	207
14	$1\frac{1}{2}$ " x 4 "	$1\frac{3}{16}$ "	" "	1,650	4	. .
16	2 " x 6 "	$1\frac{7}{32}$ "	" "	1 650	4	. . .
18	2 " x 6 "	$1\frac{3}{8}$ "	" "	1,650	4	. . .
20	2 " x 6 "	$1\frac{3}{8}$ "	" "	1,650	4	. . .
22	2 " x 6 "	$1\frac{3}{8}$ "	$\frac{3}{8}$	1,508	4.4	122
24	2 " x 6 "	$1\frac{3}{8}$ "	"	1,650	4	. . .
27	2 " x 6 "	$1\frac{7}{16}$ "	"	1,650	4	. . .
30	2 " x 6 "	$1\frac{1}{2}$ "	$\frac{1}{2}$	2,673	4.4	162
36	2 " x 6 "	$1\frac{9}{16}$ "	$\frac{1}{2}$	2,950	4	. . .
42	2 " x 6 "	$1\frac{5}{8}$ "	$\frac{1}{2}$	2,950	4	. . .
48	2 " x 6 "	$1\frac{11}{16}$ "	$\frac{1}{2}$	2,950	4	. . .
54	$2\frac{1}{2}$ " x 8 "	$2\frac{1}{8}$ "	$\frac{3}{8}$	4.600	4	. . .
60	3 " x 8 "	$2\frac{1}{2}$ "	"	4,600	4	. . .
66	3 " x 8 "	$2\frac{9}{16}$ "	$\frac{3}{4}$	6,600	4	. . .
72	3 " x 8 "	$2\frac{5}{8}$ "	"	6,600	4	. . .

SOME EXISTING PIPE LINES.

In seeking data concerning pipe lines already constructed, the author has encountered the customary indifference or unwillingness on the part of many engineers to divulge anything pertaining to the methods used in the design and execution of the work done under their supervision. Especially has this been the case where defects of a serious nature have developed. This is of course a matter for regret, since the most instructive deductions can usually be made from such experiences. Chief among the works which

might well be made instructive to the profession, but which for the above reasons is necessarily here omitted, is the 36-inch and 38-inch outfall sewer of the City of Los Angeles, Cal.

On the other hand, the author wishes to express his grateful recognition of the courtesies extended by those engineers whose appreciation of the advantage to the profession arising from a general discussion of engineering subjects by engineers has largely made possible the preparation of this paper.

From the many existing lines of stave pipe, thirteen have been selected for presentation. These, it will be observed, cover a great range in both size and pressure, and are, with some exceptions, characteristic of the best practice prevailing at the time of their construction. There would be little gained by pointing out defects in design of a nature that would be patent to any intelligent person, for which reason no cognizance is taken of any existing pipes that have been designed or constructed foolishly.

Table No. 5 is believed to be self-explanatory in the light of the previous discussion. The chief interest centers in the unit band strains used, the probable effect upon these of the swelling of the staves, and the necessary compressive resistance of the staves. Of the latter, it is of course the maxima that are chiefly interesting, and these for reasons already made plain are usually found in pipes of relatively small diameter, since with large pipes other considerations lead to lower values.

BAND STRAINS.

The factors used in proportioning the spacing of the bands, disregarding the strains induced by swelling timber, vary from 1.64 to 10.45, while the factors resulting from a consideration of the stave swelling range from 1.30 to 4.35. This latter source of strain seems to have received no recognition in design previous to 1895. Since then, in the design of the Los Angeles, Astoria, Hollister and West Los Angeles lines, a modification of the band spacings has been made for the lighter pressures in recognition of this strain, it being however ignored where spacings became less than 8 or 9 inches. On the St. Paul line, while it is not clear what general assumptions have governed the determination of the band spacings, the factors used indicate some recognition of these strains.

TABLE NO. 5.—Strains in Some Existing Pipe Lines.

No.	Location of pipe.	Date of construction.	Nominal diameters, in inches.	Length in miles.	Thickness of staves in inches.	Kind of wood.	Character of round bands.	Ultimate strength of bands.	Maximum band spacing, in inches.	Feet pressure for maximum spacing.	Minimum band spacing in inches.	Feet pressure, for minimum spacing.	Band strain from water pressure.	Band strain from least practicable cinching.	Resulting band factor, neglecting strain from swelling staves.	Band strain, from swelling staves.	Resulting factor in band, including all strains.	Least band pressure on staves per linear inch, to maintain tight pipe.	Least band pressure on staves per square inch, to maintain tight pipe.	Total probable band pressure on staves, per linear inch of band.	Total probable band pressure on staves, per square inch on band contact.
1	Denver,* Colo	1889	30	18.90	$1\frac{5}{8}$		$1\frac{1}{2}$ in. upset	11 800	12 (?)	32			2 500	538	3.90	2 010	2.34	182	729	303	1 212
	" "										2.23	172	2 500	538	3.90	373	3.46	182	729	205	820
2	Provo, Utah	1891	14	3.70	$1\frac{3}{8}$	Redwood.	$\frac{3}{8}$ in. plain	5 300	18	25			1 367	402	3.00			211	1 126		
	" "										2.75	165	1 344	396	3.00	378	2.50	208	1 108	253	1 349
3	Caldwell, Idaho	1890	54	0.13	$1\frac{5}{8}$	Pine	$\frac{1}{2}$ in plain	6 300			6.00	50	3 515	327	1.64	1 005	1.30	134	536	169	676
4	Butte, Mont	1892	24	9.00	1 7-16	Redwood.	$\frac{1}{2}$ in. upset		6	82			2 562	461	3.9	864	3.04	225	900	289	1 156
	" "										2.44	202	2 562	461	3.9	351	3.50	225	900	251	1 004
5	Bear Valley, Cal.	1893	52	0.41	2.00	Redwood.	$\frac{5}{8}$ in. upset	17 200	12	28			3 791	437	4.06	2 400	2.60	151	483	236	757
	" " "				2 60						2.00	165	3 724	558	4 00	520	3.58	150	479	168	537
6	Logan, Utah	1893	18	1.60	1 7-16	Redwood.	$\frac{3}{8}$ in. plain	5 300	12	18			844	202	5.08	1 728	1.91	100	533	266	1 417
	" "										4.00	53	828	200	5.08	576	3.30	99	525	154	826
7	Los Angeles, Cal.	1895	24	1.00	$1\frac{3}{8}$	Redwood.	*	9 000	12	25			1 562	269	4.92	1 650	2.58	137	414	260	785
	" " "										4.00	88	1 833	315	4.20	550	3.34	161	486	202	610
8	Astoria, Ore.	1895	18	7.50	$1\frac{3}{8}$	Fir	7-16 in. upset	9 000	12	25			1 166	269	5.56	1 650	2 75	138	631	297	1 358
	" "										2.25	175	1 538	352	4.76	309	4.10	182	832	212	970
9	Hollister, Cal.	1896	12		$1\frac{1}{8}$	Redwood.	$\frac{3}{8}$ in. rolled thread	6 600	10	23			599	169	8.59	1 125	3.48	108	575	266	1 417
	" "										2.75	100	716	201	7.20	309	5.38	129	686	172	918
	" "		14		1 5-32		$\frac{3}{8}$ in. rolled thread		11	22			735	182	7.20	1 272	3.01	112	600	268	1 430
	" "										2.75	100	835	207	6.33	318	4 85	128	680	167	889
10	St. Paul, Minn.	1896	42	1.50	$1\frac{1}{4}$	Fir.	$\frac{1}{2}$ in. plain	7 500	14	5			638	80	10.45	2 450	2.36	32	128	141	563
	" "										4.00	25	911	114	7.32	700	4.35	46	182	77	306
11	W. Los Angeles, Cal.	1896	30	7.50	$1\frac{1}{2}$	Redwood.	$\frac{1}{2}$ in. rolled thread	11 800	12	20			1 562	276	6.42	1 800	3.25	111	446	220	882
	W. Los Angeles, Cal.										3.50	105	2 370	355	4.33	525	3.63	165	660	197	788
12	Ogden, Utah	1897	72	5.10	2.00	Fir	$\frac{5}{8}$ in. upset	18 400	5.25	55			4 490	374	3.78	1 050	3.11	128	409	156	487
	" "										2.875	100	4 490	374	3.78	575	3.38	128	409	143	447
	" "							26 400			3.54	117	6 471	539	3.77	708	3.42	184	492	170	454
13	W. Los Angeles, Cal.	1898	14	7.50	$1\frac{1}{8}$	Redwood.	$\frac{3}{8}$ in. rolled thread	5 500	10	20			605	194	6.88	1 125	2.81	98	524	237	1 264
	West Los Angeles, Cal.										4.50	66	898	217	4.93	506	3.40	137	730	166	885

* Oval bands, $\frac{3}{8}$ in. x $\frac{1}{2}$ in., were used.

Any estimate of the strains due to the swelling of the staves under the maximum band spacing on the Provo line has been omitted. With the spacing of 18 inches under a water pressure of 25 feet, a stave $1\frac{3}{8}$ inches in thickness, a pressure of 211 pounds per lineal inch of band on the stave and a lack of hard cinching during construction, it is doubtful if such a strain exists to a considerable extent.

The Caldwell or Phillis pipe was a bold design as originally built, and is the only instance known to the author where pipe bands were actually broken by the swelling of the staves. The lumber used was Eastern Oregon mountain pine. A factor of only 1.64 seems to have been used in the spacing. On the assumption that stave swelling produces a strain of 100 pounds per square inch of contact between staves, doubtless a very conservative assumption with this class of lumber and size of pipe, and with 6-inch band spacing, this band factor would be reduced to 1.30. Uncertainty as to the exact tensile strength of the material used, and the use of a shoe of the type shown in figure 4 with the probable resulting bending of the band under the nuts, is doubtless sufficient to account for the rupture of the bands. The pipe being of large diameter, the pressure of the bands upon the staves is seen to have been too low to admit of any further yielding and consequent partial release of the band strain.

The difficulty with this pipe is said to have been remedied by largely increasing the number of bands.

COMPRESSIVE RESISTANCE OF STAVES.

The highest degree of compressive strain between band and staves necessary for the maintenance of a tight pipe seems to have been used at Provo, and the results are instructive. The ready stripping of threads due to poorly fitting nuts, prevented very hard cinching and satisfactory compression of the staves under the band. The timber was seasoned redwood. The pipe, a gravity line, is closed at the end, feeding direct into the distributing system. The use of hydrants for street sprinkling and other purposes caused a water pressure at the lower end of the line of 30 pounds above the normal, making the pressure on the staves 290 pounds per lineal inch of band under these conditions or 1,550 pounds per square inch of band contact. Leakage resulted, which was remedied by

the addition of more bands, the re-cinching of those already on, and the partial prevention of the water hammer. The upper section of the pipe, not being subject to any considerable increase of pressure over that for which it was banded, has never given any trouble, although as seen in Table No. 5 the normal pressure on the staves cannot be much less than 211 pounds per lineal inch of band, or 1,126 pounds per square inch of band contact.

On the Butte line the staves are depended upon to afford a permanent resistance against band pressure of not less than 900 pounds per square inch of band contact. At Astoria the fir staves must resist a pressure of not less than 832 pounds per square inch of band contact. Both of these lines have been successful, and the latter line especially has from the first been remarkably free from leakage. The former, by reason of the yet uncompleted condition of the storage dam which impounds the water from which the pipe is supplied, has not as yet been subjected to quite all the pressure for which it is designed.

In the smaller pipes subsequently built at Hollister, it will be noticed that much additional steel has been used in order to secure greater area of contact between bands and staves and thus keep the necessary compressive resistance of the staves down to from 600 pounds to 686 pounds per square inch. At the present time the same results might be achieved at considerably less cost by the use of bands of oval instead of round section. Such a course, as tending toward conservatism in a matter still somewhat imperfectly understood, and to partially nullify the effects of any lack of skill in erection, the author believes to be advisable in the design of the smaller sized pipes.

CONSTRUCTION DETAILS.

There are but few structural details of this class of pipe in which there is sufficient diversity of practice to warrant any discussion. The butt-joint connection, the use or omission of a bead along one edge of the stave and the coupling shoes are the only features which need to be considered.

BUTT JOINTS.

It is the prevailing practice to make the connection between the butts of connecting staves by the snug insertion of a No. 12 or

No. 14 steel plate about $1\frac{1}{2}$ inches in width, and slightly longer than the width of the stave where inserted, the plate extending slightly less than half its width into each stave. For this, in some light pressure pipes, a plate of hard wood has been substituted. The objection to the latter lies chiefly in the difficulty of forcing a thick wooden plate into the adjoining stave sufficiently to secure a tight joint, and in securing the perfect fit evidently necessary. The existing general preference for the steel plate seems justified.

PLAIN VS. BEADED EDGES.

The use of a bead on the stave is in no way vital to the success of a pipe, but seems to have strong points in its favor. If there is any irregularity in the edge of the plain stave, with band spacing suitable for light or moderate pressures, it is not possible and certainly not economical to induce sufficient fiber compression between the staves to take up those irregularities. By the use of a slight bead the compression due to cinching is at first concentrated on the bead forcing it into the adjoining stave, and thus a uniformly tight seam is secured without the necessity for hard compression throughout the entire contact area that exists in the other case. Furthermore the bead adds nothing to the cost of the stave.

COUPLING SHOES.

Not a little ingenuity has been displayed in devising various types of coupling shoes, the desideratum being that with the least cost the shoe should have an ultimate strength fully equal to that of the band, a sufficient and properly distributed bearing surface to withstand high strains without destructive crushing of the stave, and admit of speedy placing and the ready adjustment of the band during erection.

In the following discussion only those types are considered which have separate characteristics, are the better of those that have been employed, and which have already met, or promise to receive, the greatest measure of favor.

The various devices in use may be divided, with reference to the manner of engaging the two ends of the band, into two general classes:

(1) Those which engage the two ends in the same transverse plane as Figs. 1, 2 and 3.

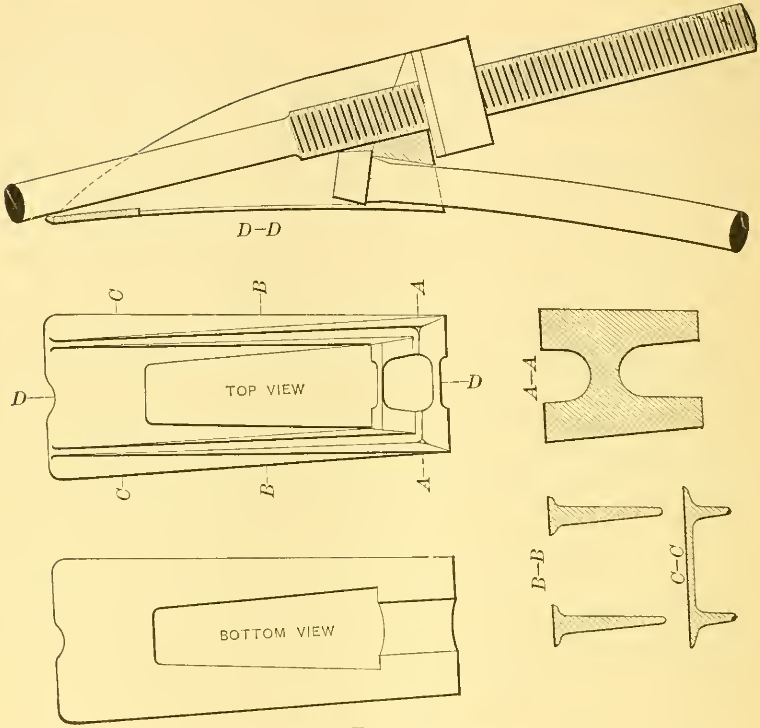

D–D
C
B
A
D
TOP VIEW
D
A–A
C
B
A
B–B
C–C
BOTTOM VIEW

Fig. 1.

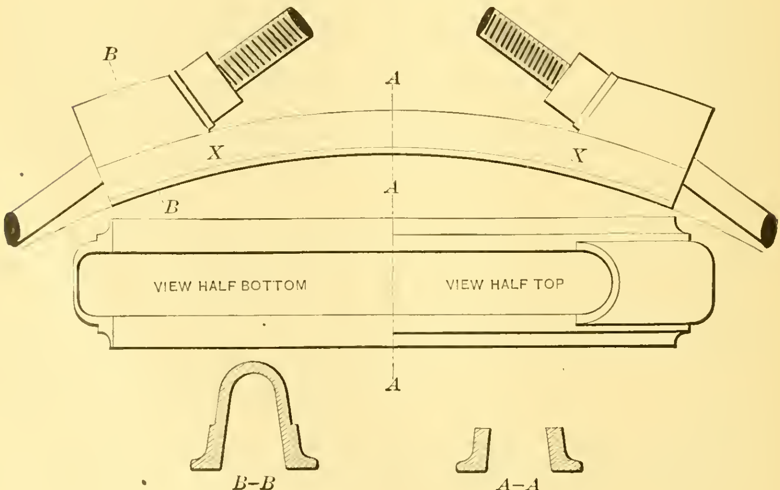

B
A
X
X
A
B
VIEW HALF BOTTOM
VIEW HALF TOP
A
B–B
A–A

Fig. 2.

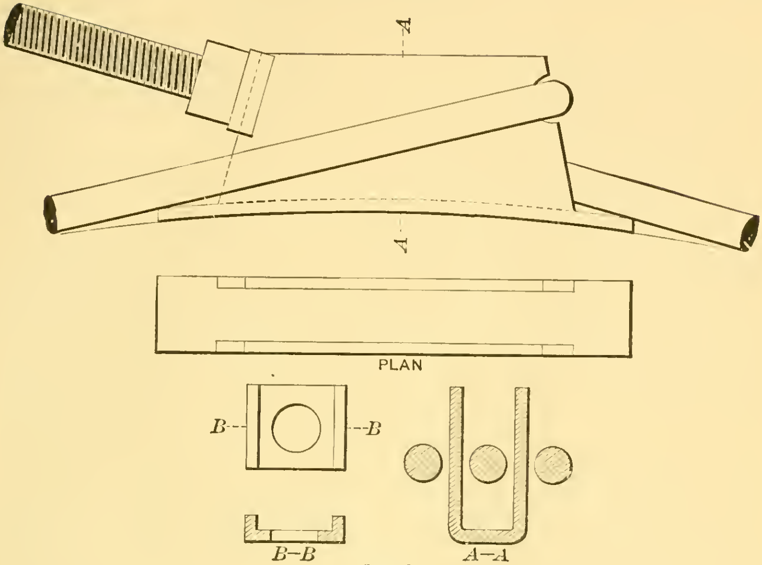

A
A
PLAN
B
B
B–B
A–A

Fig. 3.

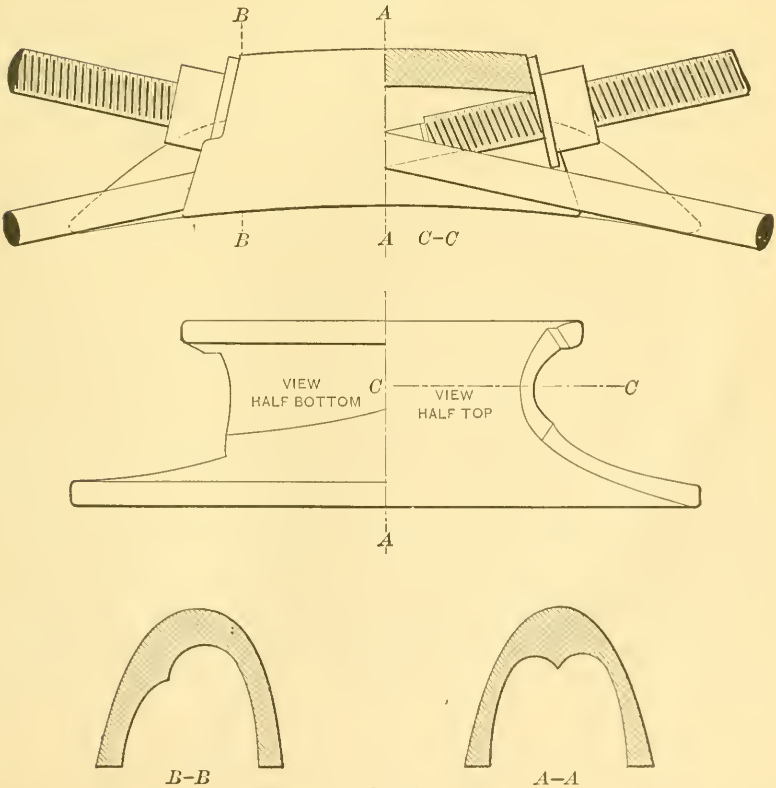

B
A
B
A
C–C
VIEW
HALF BOTTOM
C
VIEW
HALF TOP
C
A
B–B
A–A

Fig. 4.

(2) Those in which the ends are not engaged in the same transverse plane, as Fig. 4.

With reference to the materials of which they are made, they may be divided into:

(1) Forged, as Figs. 2 and 3.

(2) Cast, as Fig. 4.

(3) Malleable cast, as Fig. 1.

Fig. 1 is the general form of shoe that has been largely used by the Excelsior Wooden Pipe Company, it having been evolved from, and being representative of, the type originally used in the construction of the Denver lines. When properly proportioned this shoe admirably meets all the requirements for a successful connection, and in the economical distribution of the material for resisting the strains imposed leaves little to be desired, and possesses much to be admired. It will be noted that by the use of a T-head, the nut is brought as low as possible, and the resulting moment tending to produce rotation about the centre of the head bearing is thus reduced to a minimum. The length and ample bearing of the shoe enables the stave to resist this tendency without destructive pressure. The flanges on the lower edges of the ribs afford bearing surface and give sufficient sectional area to resist the tensile strains here existing, while in height the ribs are well proportioned for transmitting the band strain to the staves. It will also be observed that the shoe permits the use of the wrench without interference. The feature most open to criticism in the design of this shoe as generally used is the tendency to make insufficient allowance in its weight for the deterioration of such light sections.

Fig. 2 shows a shoe of a type that has been used in a number of instances on the Pacific coast. It is a forging from a rolled section. The length of the shoe in the rear of the nuts is wholly insufficient to afford the proper degree of bearing surface on the staves to safely resist the pressure; and the bending strain at x, due to the depressing of the end of the shoe into the stave, can only be resisted by the use of a much heavier section than the tensile strains alone require, or prevented by giving more supporting area under the ends. It is evident that the fault lies in the use, unavoidable here, of low connecting ribs.

Fig. 3 is a forged shoe of the type used on the recently completed works of the Pioneer Power Company at Ogden, Utah. In most

respects the form is evidently well calculated to economically resist the imposed strains; but as it necessitates the use of a welded loop on one end of the band, the shoe can scarcely compare in economy with some of the other types, unless, indeed, the relative cost is very largely influenced in its favor by royalty charges on the other shoe. The details of the loop bearing on the shoe are perhaps not beyond the suggestion of improvement, as there appears to be possible lack of stiffness, which, however, could be readily remedied by the insertion between the loop and shoe of a properly designed compression lug of cast iron. It would also appear that the cost of the entire shoe might be somewhat reduced without sacrifice in other respects by modifying the design and making it of cast or malleable cast iron, for which materials the general shape of the shoe, as affecting the strains, seems especially well suited.

Fig. 4 is of that class which does not engage the ends of the bands in the same vertical plane. There being thus introduced a cross strain or tendency to rotate about an axis vertical to the center of the shoe, it is difficult to devise a really efficient and economical design. It is usually sought to resist this tendency to rotate by means of the friction afforded by long tapering extensions at each end of the casting, as in the figure shown. This device has generally been found insufficient, hard cinching usually resulting in the breaking of the tail-piece or the rotating of the shoes and the bending of the bolts. These difficulties can, of course, be corrected by the use of very large, heavy shoes, but with a resulting cost much beyond that of other and better types. This general style of casting seems to have been the first used in stave pipe construction with round bands, and has had quite an extended application in recent years, though frequently with unsatisfactory results. The particular design shown is that adopted in the construction of the Los Angeles outfall sewer, in the spring of 1894, and in detail is the best of its class that the author has seen. Nevertheless, it was found to possess the defect inherent in the type, many having broken under even the reputed light and insufficient cinching used on that work.

In conclusion, it appears to the author that the essential requirements of a safe and economical design are much more successfully worked out in Fig. 1 than in any of the others.

THE ECONOMY OF ITS USE.

In seeking to set forth clearly the real place of stave pipe in the economic design of pressure conduits, it is essential that the conspicuous types of pressure pipes be briefly considered in their relation to each other. The three varieties to be contrasted herein are stave, steel riveted and cast iron. Welded pipe is omitted because it occupies an intermediate position and does not affect the merits of the discussion. The comparison will be confined to the pressure range of practical stave pipe construction, say not to exceed 100 pounds per square inch, for which pressure each of the classes mentioned may be assumed to be wholly applicable.

Previous to argument, the relative standing of each, in the order of their merit with reference to the three most important qualifications, the author tabulates as follows:

Cost.	Life.	Capacity.
(1) Stave.	Cast iron.	Stave.
(2) Steel riveted.	Stave.	Cast iron.
(3) Cast iron.	Steel riveted.	Steel riveted.

If the quantity of water delivered, instead of the diameter, were made the common basis of comparison for the different pipes, the capacity would become a function of the cost, an aspect briefly considered later. For the present they will be considered separately.

LIFE.

Passing temporarily over the question of cost and taking up that of comparative duration, it may be assumed at once that cast iron should be given the preference, not, indeed, as conclusively proven by experience, but as in every way probable, since the bands of the stave pipe, excepting perhaps in the larger sizes, can hardly be supposed to have the same degree of endurance as the thick shell of the cast pipe.

In placing steel pipe last, the author is influenced by the following considerations:

(1) That the sheet metal from which the pipe is made is of less thickness than the diameter of the stave pipe bands, a condition always existing in steel pipes subject to the comparatively light pressures here considered.

(2) That the same degree of care in securing protection of the metal can be exercised in both cases.

(3) A properly proportioned steel pipe does not eventually fail by bursting, but by the formation of rust holes and attendant leakage. The considerable multiplication of such holes soon causes a new pipe to be cheaper than the necessary repairs, even though $\frac{995}{1000}$ of the metal in the pipe may be as good as when it was laid. The life of a steel pipe may, therefore, without material error, be said to be measured by the life of its weakest spots.

(4) The life of a stave pipe is probably determined by the life of the bands ; and the life of the bands is determined, not by the time necessary for the formation of local rust pits, even though they are very deep, but by the reduction of the entire band section until its ultimate strength is exceeded by the strain, say to less than one-fourth its original section. It seems clear that the time requisite to accomplish this degree of deterioration in the sections generally used, must be many times that necessary to accomplish the destruction of the average light gauge riveted pipe.

(5) Many cases on the Pacific coast might be cited where steel pipe of the lighter gauges, though carefully coated with asphalt, and apparently laid with reasonable care, have rusted through in from eighteen months to three years, and have been shortly afterwards abandoned.

(6) Should a perfect and reasonably cheap protective coating for steel ever be discovered—an improbable assumption—no single class of pipe would have much advantage over another in respect of durability.

(7) It is certainly in accord with universal engineering experience to assume that wood, under the conditions prevailing in proper stave pipe construction, is practically indestructible; and much direct evidence in harmony with this assumption has accumulated from the many instances of the use of stave and other wood pipe construction which have done service in America for from twenty to fifty years, and as far as the author knows, without an instance of failure from the decay of staves where the proper requirements were observed.

The author does not wish to be understood as intimating that steel pipe is always short lived. On the contrary, many such pipes where conditions are favorable have been doing excellent service for many years; but the exceptions are instructive, and fully vindicate the position assumed by many engineers, who for permanent

work have recognized the necessity for a considerable thickness of metal independent of the demand for a sufficient factor of safety against bursting, and who accord little favor to pipes of very light gauge.

The foregoing seems to the author to be ample justification for placing the stave pipe far in advance of the steel pipe for durability under average conditions.

CAPACITY.

The past few years have added much to the knowledge of engineers concerning the carrying capacity of cast iron and particularly of steel riveted pipes of various diameters. The relative values of each class as economic carriers of water, are better understood than ever before. The general result of experiments on cast iron pipe has been to prove the value of the Kutter formula in showing the value of "n" to be practically a constant for any given diameter, degree of surface roughness and velocity of flow. In the case of steel riveted pipes, whether built with cylindrical or taper joints, with few exceptions the results indicate that the Kutter formula does not apply, and that for the ordinary ranges of velocities, say from 3 to 6 feet per second, for clean pipes the coefficient c in the formula $v=c\sqrt{r\ s}$ is nearly a constant for all diameters; and if the experiments on the Portland, Ore., pipes are excepted, because of inability to harmonize them with others, it is not clear that the results are much affected by variations in the thickness of the plates, within the range of ordinary usage.

These experiments, while still leaving much to be desired before attempting the formulation of any positive rules for the exact preliminary determination of the rate of flow in any given case, a result which the author believes will not be accomplished save within limits of a very narrow application, because of the usual unavoidable lack of similarity in the influencing physical conditions, are sufficient to accomplish the complete upsetting of many previously conceived ideas regarding the laws of flow in this class of pipe. The failure of "c" to increase as the diameter increases, places the value of this pipe as an efficient water carrier, at least for the large diameters, in a relation to pipes having approximately smooth interiors, totally different from that which it has previously been accorded.

The dissipation of the once prevalent idea that wrought iron and steel pipes are not subject to tuberculation, and the later conviction that in this respect they have little or no advantage over cast iron, have also done much to make possible a better estimate of the real merits of this pipe.

The author regrets that as yet so few experimental determinations of the carrying capacity of stave pipe under varying conditions of diameter and grade have been made. In engineering literature he knows of only four in which the proper conditions have been sufficiently observed to render them worthy of mention. They are as follows:

(1) An experiment on a long line of 30-inch pipe (No. 1, Table 5) briefly mentioned by J. D. Schuyler, M. Am. Soc. C. E. In this case, with a mean velocity of about 2.33 feet per second, the derived value of n in the Kutter formula was found to be a little less than 0.010.

(2) An experiment by the author on an 18-inch pipe (No. 8, Table 5), in which the value of c in $v = c\sqrt{rs}$ was found to be 133, with a mean velocity of 3.60 feet per second. This result corresponds to a value for n in the Kutter formula of a little less than 0.010.

(3) Experiments on a section of 6-foot pipe (No. 12, Table 5), described by Charles D. Marx, M. Am. Soc. C. E.; Charles B. Wing, Assoc. M. Am. Soc. C. E. and Leander M. Hoskins. The results gave average values for c as follows:

Velocity in Feet per Second.	Corresponding Value of c.
1.0	97
2.0	115
3.0	122
4.0	126

The values of n corresponding to these results vary from 0.012 to 0.015.

(4) Experiments by the author on a line of 14-inch pipe (No. 13, Table 5), in which the values of c averaged as follows:

Velocity in Feet per Second.	Corresponding Value of c.
0.7	102
1.2	111
1.5	112

The values for n corresponding to these results vary from 0.0107 to 0.011. The velocities, it will be observed, are all very low.

The results of the Ogden experiments are so much at variance with the great preponderance of credible evidence bearing on this question, that without wishing to seem to discredit them, the author awaits further verification of the results before accepting them as conclusive.

In Table No. 6, showing the values of c in the formula $v = c\sqrt{r\ s}$, for clean pipes of staves, cast iron and lap-riveted steel, the values for the stave and cast iron pipes are deduced by aid of the Kutter formula, assuming a value for n of 0.010 for the stave pipe, of 0.011 for the cast pipe when clean, and 0.014 when tuberculated, a velocity of flow of 3 feet per second being assumed. For steel riveted pipes the uniform value of 111 is given for c for all diameters, and a deduction of 20 per cent. is made in determining the values for tuberculated pipes.

The calculated values are for the most part interpolated from tables, and may be slightly in error in the last figure.

The most that the author claims for the assumptions on which these tables are based is that they are in substantial accordance with the best of our experimental knowledge; and that when such knowledge is wanting one can do no better than to rely upon the Kutter formula. Future investigation will doubtless necessitate many modifications, but will scarcely change the designated order of relative efficiencies.

TABLE NO. 6.—Values of c in the Formula $v = c\sqrt{r\ s}$ for Clean Pipes of Wood, Cast Iron and Riveted Steel; and for Cast Iron and Steel Riveted Pipes When Tuberculated.

Diameter.	Stave.	Cast iron.		Steel riveted.	
	n 0.010.	Clean. n. 0.011.	Rough. n 0.014.	Clean.	Rough.
12	119	105	77	111	89
18	130	117	86	111	89
24	137	123	92	111	89
30	143	129	97	111	89
36	148	133	101	111	89
42	152	136	105	111	89
48	154	138	108	111	89
54	157	140	110	111	89
60	159	142	112	111	89
66	161	144	114	111	89
72	163	146	116	111	89

If the discharging capacity of the stave pipe of any diameter is designated as 100, the relative discharging capacities of the others will be as follows:

TABLE NO. 7.—RELATIVE DISCHARGING CAPACITY OF PIPES, STAVE PIPE BEING TAKEN AS 100.

Diameter.	Stave.	Cast iron.		Steel riveted.	
		Clean.	Rough.	Clean.	Rough.
12	100	88	65	93	74
18	100	90	66	86	69
24	100	90	67	81	65
30	100	90	68	78	62
36	100	90	69	75	60
42	100	90	69	73	58
48	100	90	70	72	58
54	100	89	70	71	57
60	100	89	70	70	56
66	100	90	71	69	55
72	100	90	71	68	54

If the premises are correct, and they are believed to be in harmony with present knowledge, these results are of a startling nature. Clean cast iron pipes would seem to have about 90 per cent. of the carrying capacity of stave pipes, while if seriously tuberculated, a condition which usually prevails after a few years of use, they discharge only about two-thirds as much as stave pipes of the same sizes.

The steel pipe discharges, when clean, from 93 per cent., in case of a 12-inch pipe, to 68 per cent. in case of a 6-foot pipe, of the amount which might be expected from stave pipes of the same sizes, while if the steel pipe is tuberculated to an extent that may readily occur in from ten to fifteen years of use, these discharges may fall to 74 per cent. and 54 per cent., respectively.

Omitting other considerations, is not the value of a pipe line investment proportional to its delivering capacity? Do not these percentages then represent approximately the relative values of these different classes of pipes as investments?

COST.

Variability in market quotations on materials, freight rates, wages, the effect of geographical location of these, the conditions affecting

hauling and the manner of executing the work make it impossible to deduce an accurate comparison of cost which will admit of general application. For present purposes, however, it is not necessary to attempt more than to convey a general idea of the order of the respective costs of the three classes of pipe considered, at the terminal points designated. For this purpose Tables Nos. 8 and 9 have been prepared with considerable care.

It is assumed that the stave pipe is designed in accordance with the formulas previously deduced, an assumption which somewhat increases the cost, particularly for light pressures, above that which would result were the bands spaced in accordance with the formulas more commonly used.

The steel pipe is supposed to be double riveted on the straight seams and single riveted on round seams as ordinarily built, and coated with asphalt. The mill price for sheet steel is taken at from $1.60 for No. 14 plate to $1.25 for thicknesses greater than No. 8.

The cast pipe is supposed to be proportioned as to thickness by the formula of the Warren Foundry, and the prices assumed per ton are $19 at Chicago and $26 at San Francisco, the latter figure being the lowest yet quoted there.

TABLE NO. 8.—Comparative Cost of Pipe at Chicago.
Including Laying but Omitting Haul.

	Stave.				Steel riveted.								Cast iron.			
Nom. diameters.	25-ft. head.	50-ft. head.	100-ft. head.	200-ft. head.	No. 14 B. W. G.	No. 12 B. W. G.	No. 10 B. W. G.	No. 8 B. W. G.	No. 6 B W. G.	$\frac{1}{4}$ inch.	5-16 inch.	$\frac{3}{8}$ inch.	25-ft. head.	50-ft. head.	100-ft. head.	200-ft. head.
12	.42	.49	.63	.85	.32	.38	.44						.73	.77	.84	1.00
18	.69	.80	1.02	1.46		.57	.65	.78	.98				1.29	1.35	1.46	1.70
24	.79	.91	1.14	1.61			.85	1.04	1.28	1.55	1.99		1.91	2.00	2.18	2.55
30	.96	1.12	1.44	2.06				1.27	1.59	1.93	2.46	3.04	2.67	2.80	3.07	3.61
36	1.19	1.40	1.82	2.65				1.55	1.93	2.30	2.92	3.58	3.47	3.67	4.06	4.85
42	1.40	1.68	2.23	3.33				1.61	2.18	2.66	3.37	4.12	4.42	4.69	5.22	6.28
48	1.55	1.85	2.46	3.67					2.48	3.03	3.83	4.66	5.50	5.84	6.53	7.92
54	2.23	2.62	3.43	5.02					2.80	3.41	4.29	5.21	6.65	7.10	8.00	9.78
60	2.85	3.35	4.37	6.40						3.79	4.75	5.74	8.04	8.63	9.80	12.13
66	3.21	3.81	5.00	7.38						4.35	5.21	6.29	9 51	10.16	11.55	14.05
72	3.65	4.38	5.83	8.73						4.52	5.66	6.83	11.32	12.00	13.26	16.00

Comparative Cost of Pipe at San Francisco.

Including Laying but Omitting Haul.

	Stave.				Steel Riveted.								Cast Iron.			
Nom. Diameters.	25 ft. Head.	50 ft. Head.	100 ft. Head.	200 ft. Head.	No. 14 B. W. G.	No. 12 B. W. G.	No. 10 B. W. G.	No. 8 B. W. G.	No. 6 B. W. G.	¼ inch.	5-16 inch.	⅜ inch.	25 ft. Head.	50 ft. Head.	100 ft. Head.	200 ft. Head.
12	.37	.45	.61	.94	.45	.52	.60						.94	.99	1.09	1.31
18	.58	.71	.96	1.47		.77	.88	1.04	1.30				1.65	1.73	1.89	2.21
24	.76	.96	1.35	2 12			1.01	1.35	1.67	1.97	2.51		2 50	2 62	2.86	3.37
30	.83	1.03	1.43	2 23				1 64	2 04	2 45	3.10	3.79	3.52	3.70	4.07	4.81
36	1.02	1.29	1 83	2.90				1.80	2.44	2.92	3.67	4.49	4.60	4.87	5.40	6 50
42	1.23	1.58	2.28	3 69				2.27	2.80	3.37	4.24	5.12	5 87	6.25	6.97	8.43
48	1.34	1.73	2.51	4.07					3.14	3.80	4.78	5.78	7.33	7.80	8.73	10 64
54	1.94	2 45	3.49	5.52					3.55	4.32	5 37	6 47	8.86	9.47	10.69	13.15
60	2.44	3.09	4.39	7.00						4 87	5.95	7.24	10.73	11.54	13.14	16 33
66	2.79	3.57	5.14	8 26						5.43	6.54	7.81	12.70	13.69	15 45	18 92
72	3.22	4.15	6.04	9.78						5.90	7.09	8.50	15 12	16 05	17.78	21.53

The figures are supposed to include only the principal common items of expense, with no profit to the contractor. They are therefore, perhaps, in every case somewhat below probable cost, and are intended for use by way of comparison only.

A contrast of actual quotations for particular cases would, in almost every instance, show a greater advantage to the stave pipe than the tables indicate. Especially would this be true where a considerable haul would be necessary, or where the work is far removed from pipe shops and of insufficient magnitude to justify manufacturing the riveted pipe on the ground, or where the site is difficult of access. The tables indeed assume the most favorable conditions for the use of the steel riveted or the cast pipes.

While cost, durability and carrying capacity chiefly characterize the efficiency of a pipe line and determine its value as an economic investment, there are lesser considerations which are of peculiar interest in relation to stave pipe. Two of these — ease of repair and extent of unavoidable leakage — the author wishes to briefly consider before closing this paper.

EASE OF REPAIR.

The manner of its construction in being built of independent staves held together by removable bands, makes possible the taking out of defective staves and, if need be, the replacing with new materials of entire sections at any point on the line, without other tools than a saw, square, wrench and flat chisel, and with remarkable dispatch. Two striking instances illustrating the facility and speed with which such repairs can be made have come to the author's attention: On the Astoria gravity line, 18 inches in diameter, before backfilling was completed, a large fir tree fell across the trench, broke in two, and one section descended endwise upon the pipe, crushing in and destroying the top staves. The accident was not discovered until the pipe up to this point was filled with water. One man made the repairs and had the water flowing under full head — about 70 feet — in two hours after the tree was removed from the trench. One of the 4-foot syphons on the conduit of the San Gabriel Power Company was crushed to pieces by the falling from the mountain-side of a large boulder. The repairs were made and pipe ready for water within four hours after the removal of the obstructing rock. Such results must strongly appeal to engineers familiar with the maintenance of such structures, and having knowledge of the usual seriousness of delay in accomplishing repairs. In the correcting of small leaks it is seldom necessary to do more than insert a few small wedges.

EXTENT OF UNAVOIDABLE LEAKAGE

The question of leakage in this class of construction is most interesting; and in the constructing of very long lines designed for low velocities may become of the greatest importance.

There can be little doubt that careless construction will usually result in excessive leakage, as is indeed true of any class of pipe. The important question, rather, is: to what extent is leakage unavoidable with skillful construction? The author has knowledge of results secured in two instances on work built under his supervision: One at Astoria, an observation of an assistant engineer, the other a carefully conducted test on a 14-inch extension of the system of the West Los Angeles Water Company supplying the Pacific Branch of the National Soldiers' Home with water, mentioned on page 38. In the first before-mentioned, the upper 2½

An Accident That Was Repaired in 4 Hours.

miles of the 18-inch gravity line built of yellow fir stave, was filled with water. The gate at head was not wholly tight but admitted a trickling stream insignificant in amount. The lower end terminated at a gate with a relief overflow two feet above the hydraulic grade line. The small trickling stream entering at the upper end was observed to be passing out of the overflow at the lower end, apparently undiminished in volume. The intervening pipe in accordance with proper practice was all located well below the controlling summits, that it might be under pressure at all stages of flow.

In the second instance, the pipe had been in use for some months at the time of test. The location, as in the first case, was such as to cause the pressure, excepting at occasional short summits, to be little affected by the rate of flow. A section of the line four and one-half miles in length, having a permanent 4-foot weir at each end, was experimented upon. Hook gauges set in the masonry structure at each point were used in measuring heads. In the first experiment, the rate of flow was reduced to a discharge of about one inch in head on the weir, without being able to detect any certain loss. A temporary weir but eight inches in length was then substituted for the 4-foot weir in each case, and the discharge reduced to a head of about an inch, and again no diminution could be observed at the lower weir. The experiments were continued for a number of hours that there might be no doubt as to the minimum constant discharge being secured. The delicacy of this latter test was such that, with due allowance for the usual small unavoidable errors in such experiments, the author felt justified in pronouncing the pipe practically without leakage.

CONCLUSION.

If, then, stave pipe stands unquestionably first in point of both first cost and carrying capacity when contrasted with the two other classes of pipe usually considered, not to mention less vital constructive advantages, and second only to cast iron in length of life, does it not logically follow that it is destined to a greatly extended use? And is it not clear, that though the great saving in first cost incident to local causes has fostered its rapid introduction in the West, yet the field of its economic usefulness is by no means compassed by such narrow limits? If these querries are answered in the affirmative, is it not deserving the careful consideration of en-

gineers who conscientiously and studiously seek a wise economy in the design and execution of hydraulic works?

DISCUSSION.

By Chas. K. Walker, Superintendent.

As a desire has been expressed for a description of the stave pipe built by J. F. Fanning, C. E., at Manchester, N. H., the following is submitted:

No examination has been made of the pipe since it was built, in 1872, but from reports and descriptions by Col. Fanning it appears that the pipe extends from the canal to the turbine wheels in the pumping station, a distance of 600 feet. It was made of hard pine staves, 4 inches thick, laid so as to break joints, and hooped with $2\frac{1}{2}'' \times \frac{5}{8}''$ wrought iron hoops spaced eighteen inches apart. The hoops were made in two pieces, which were bolted together with $1\frac{1}{2}''$ bolts. The butt ends of the staves were made tight by a sheet of steel inserted in saw cuts in each end. This steel projected slightly beyond the edge of the stave and penetrated the adjoining stave. At two slight changes in grade in the pipe butt joints are made which are covered with wrought iron hoops. The pipe is under 12 to 40 feet head, and is covered with about 6 feet of earth.

The pipe has never leaked, and has never been uncovered except at one place for the insertion of a stop cock, where it was apparently sound.

By W. H. Richards.

It may be of interest to say that a 24-inch submerged sewer 900 feet in length was built under the direction of the writer in New London, Conn., in 1892, of cypress staves secured by $\frac{3}{4}''$ galvanized round steel hoops. The butt joints being secured in this instance by wooden trenails or "stop waters" driven into a hole bored through the joint on a line tangent to the radius. This proved to be a very easy and effective way to secure the butt joints. This sewer being laid under the bottom of the harbor in salt water and mud, the wooden pipe was selected not only because it could be more easily laid, but because it was considered to be more durable than any metal pipe would have been under the conditions which obtained.

IMPROVED WYCKOFF WATER-PIPE.

BY GEORGE L. WELLS, CIVIL ENGINEER, BAY CITY, MICH.

[*Read January 11, 1899.*]

Improved Wyckoff water pipe is made of wooden shells bored and turned, from solid logs and banded spirally with iron, steel or bronze bands to provide the strength. The outside is thoroughly coated with pitch by rolling the finished pipe on steam heated rollers which work in a bath of melted pitch maintained at about 350 degrees F. After being coated the pipe is rolled on a bed of sawdust or planer shavings and then smoothed on cold rolls. There are two manners of making joints. For low pressure pipe a mortise four inches long is bored in one end of a length and a tenon to make a tight fit is turned on the other end. For high pressure pipe, such as is used in municipal water works systems, a mortise is bored in both ends of the shell and a wood thimble, usually made from white pine thoroughly seasoned, with the same inside diameter as the pipe and with an outside diameter one-eighth of an inch larger than the diameter of the mortise into which it fits. After forming the joints and just before coating the outside, each piece of pipe is tested under pump pressure from forty to two hundred pounds per square inch according to the weight of banding and the service for which the pipe is designed.

Such in brief is a description of the pipe and its manufacture, details of which will be more fully discussed.

ORIGIN OF NAME.

In 1860 a patent was granted to Mr. A. Wyckoff of Elmira, N. Y., for an augur which bored a log taking out a core, so that a number of concentric pipe shells could be bored from one log. The name "Improved Wyckoff Water Pipe" has been adopted by the other manufacturers who have made improvements both in the methods of manufacturing and in the pipe itself.

DURABILITY.

In selecting a pipe for a system of water works the question of durability is one of prime importance, and the selection or rejection of any form of pipe is usually decided according to the purchasers' opinion of the durability.

Investigation into the durability of improved Wyckoff water pipe has been made almost entirely as to the life of the wood in the shells. When that question is settled very little doubt exists as to the other merits claimed for the pipe.

It is a well known fact among people who work with timber that when the sap is taken out of it—the fibre freed from albumen, starch, sugar, etc., contained in the sap, which ferment and promote the life of germs which cause the decay—that the fibre is practically imperishable. Every process for the preservation of timber depends entirely upon the extraction of the sap. Anticeptics used to preserve the wood simply kill or ward off the attacks of extraneous germs which would feed upon it.

When Wyckoff water pipe is placed in a water works system, water is forced into all the pores of the wooden shells. The supply is constant and the water in the pores is continually though gradually renewed. By this means all the sap in the shell is dissolved and washed out leaving the wood "seasoned." The writer is aware that the popular understanding of the word "seasoned" when applied to wood, implied that the sap has been taken out by exposure to the wind, heated air, or extracted in a vacuum, all of which leaves the timber dry, but he believes that experienced engineers generally use the term to denote timber which has been freed from sap whether wet or dry, and it is used in that sense here. Logs which have been floated from the forests to the mills, and which have laid in water long enough to have it displace the sap, are found to make lumber which seasons more quickly and thoroughly than lumber made from logs hauled to the mills by teams or railroad.

That the water fills the pores of the wooden shells of Wyckoff pipe more thoroughly than the sap did while they were in the trees is evidenced by the fact that the shells become much harder and firmer after they have been used in water mains.

In other branches of engineering, timber is made use of extensively where durability is all important. Its extensive use as piling and for crib work in foundations for bridges, large and costly permanent buildings and in river and harbor improvements is too well known to need discussion here. It is simply referred to here to call to mind the great use made of timber where the conditions are very similar to those under which timber is used in Wyckoff pipe. In a water works system where the pressure is 43.4 pounds per square inch the pores are as thoroughly filled as if submerged in 100 feet of water, etc.

It is recognized that in order for timber to decay there must be three conditions existing at the same time, viz: a temperature from 50 degrees to 150 degrees F., in the presence of air and with the timber in a moderate condition of moisture. The absence of any one of these conditions makes decay impossible. When used in the shell of a water pipe, the only one of these conditions affecting the wood is that of temperature.

Besides the foregoing reasons for believing that wood used in the shell of a water pipe is a durable material, we have the experience of the pipe to prove it. The system of water works at Bay City, Michigan, was constructed in 1872. Additions have been made until there are now about 35 miles of Wyckoff pipe made use of in the system. During the past summer while some street improvements were being made, the writer had the opportunity to examine some of the first pipe laid and it was found to be in a perfect state of preservation. A large number of towns in the .middle and western states have had a similar experience. Unfortunately the early makers of the Wyckoff pipe had not perfected means for banding the pipe securely, and there were some failures of the pipe for the lack of strength on this account. In 1870 Mr. M. F. Wilcox of Bay City, Michigan, designed and patented a machine with an automatic brake which applied the band under a tension so that all trouble of that kind was eliminated.

In the eastern cities of the United States, about 100 years ago, there were quite a large number of water works systems constructed using bored logs for mains. The logs were not turned and many times the bark was not taken off. The logs were not banded. The great thickness of wood left about the bored hole

was depended upon for strength. Various sorts of devices were used for joining lengths of these crude pipes together. As population increased and there was demand for greater pressures than these old log pipes would stand, they went out of use. But these old log systems bear evidence that wood is well adapted for use in the manufacture of water conductors. Within the last three and a half years the writer has seen the old bored logs used in the Jamaica Pond system in Boston, in the old Manhattan system in New York and in the old system in Philadelphia. These old bored logs had been recently taken out of the streets and although they had not been in use for a number of years, they were in a remarkably good state of preservation. The pipe of the old Jamaica Pond water works system was taken out of Harrison Street in Boston, where excavations were being made for conduits for electric light wires in the summer of 1895. One of the workmen had cut the pipe with an ax and the interior timber was as bright and fresh looking as that of a newly cut log. Trautwine's Engineer's Pocket Book, Edition of 1882, page 577, says that pipes which had been laid 50 or 60 years were relaid in factories, etc. At Fayetteville, N. C., a system of water works was constructed between 1820 and 1823 using three-inch bored logs under a head of about forty feet. In December, 1893, the Superintendent of the Fayetteville works sent a sectional block which he had cut out of one of these logs a few days before. In the letter accompanying the block he stated that the block had been in pipe which had been in continual use for at least seventy years. The block was in a perfect state of preservation. The block is still in the writer's possession and is bright and sound and does not show any sign of decay.

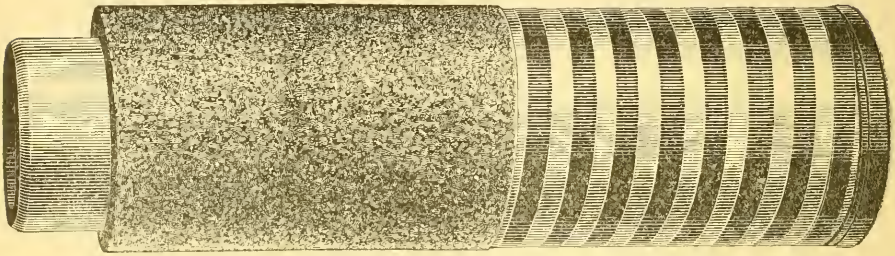
Other points of the general durability of improved Wyckoff water pipe will be discussed or referred to later.

STRENGTH.

The standard width of bands is one inch. Various thicknesses of bands are used which are spaced from one-half inch to four inches between the spiral wrappings according to the strength required.

For extremely light pressures of ten pounds or less the ends only are banded.

The cut of the pipe shows one end coated and the bare band and shell at the other end. A thimble for connecting lengths together is shown on the left end of the cut. The cut, however, is defective in one respect, as it does not show the band run doubly over the entire length of the mortise.



The spiral bands are applied to the wood shells in a machine with an automatic brake referred to above, and are fastened only at the ends. The band is started a few inches back of the mortise by driving the end into the shell. It is then wrapped over the entire circumference at that point, then run spirally to within half an inch of the nearer end, then back over the whole length of the pipe to within half an inch of the other end, then run back over the mortise and fastened to the shell with screws designed for that purpose. These fastenings, though simple, have been found to be secure and reliable.

Bands are now, and have for some years, been made of Bessemer steel having a tensile strength of 70,000 pounds per square inch. Tobin bronze bands have been used on some pipe where mineral waters containing large quantities of compounds of sulphur were to be conveyed from mineral springs to points where they were to be used. With the wooden shell and bronze band there is nothing about such pipe for which sulphur has an affinity, and it has worked very successfully.

The steel bands and wood of the shell both being elastic enables the pipe to withstand the shock due to the water rams and pounding of pumps. Some years ago, to see just how this would work in practice, the writer made an experiment. A length of 160-pound test-pipe 6 inches in diameter was put into a hydraulic test-

ing apparatus, and the pressure run up to 350 pounds per square inch when the wood shell split nearly midway between the ends. The split was about a foot long and less than an eighth of an inch wide at the centre. The pressure was held at 350 pounds for a few minutes. The size of the split did not increase. It seemed to act as a safety valve, so to speak. As the pressure was gradually reduced the split became narrower. At 120 pounds it was closed, but small drops escaped—possibly a pint a minute. At 100 pounds water could just be seen oozing from the split, and at 80 pounds it was so tight that there was no water escaping from it.

This feature of the improved Wyckoff water pipe is one that makes it well adapted for the mains in a gravity or direct pressure system of water works where the head or pumps supply a fire pressure, as the shock from the interrupted flow or pounding of the pumps will be largely dissipated in the elastic walls of the pipe, and in case of a shock great enough to cause a rupture, the wood will split and permit water to escape until the normal pressure is again reached, when the split will close without any inconvenience being experienced, and without interfering with the work of the fire department. The writer does not know of any of this pipe breaking which caused any flood or washouts in the streets. The break in the wood when it occurs relieves the bands from excessive pressure, and they are able to stand the strain put upon them.

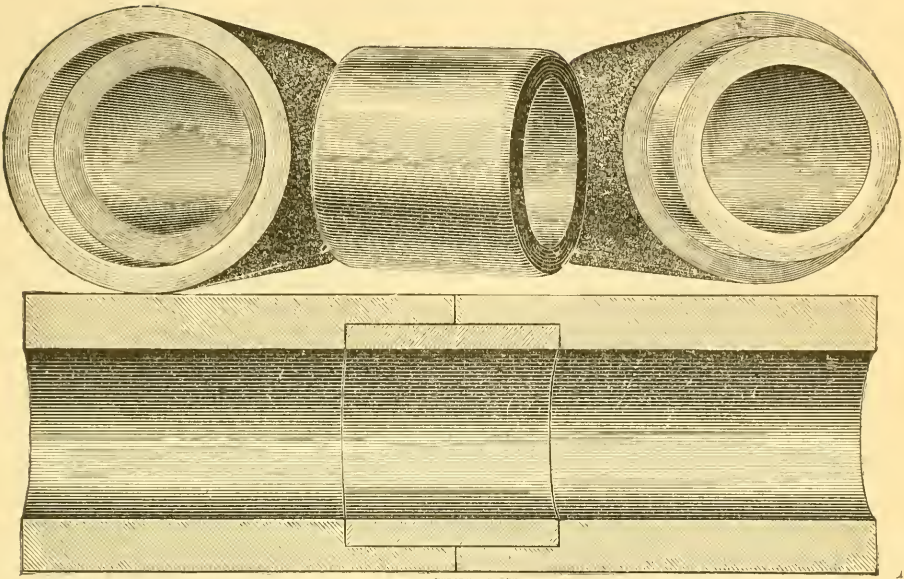
The pipe is designed for the entire strain due to the pressure to be carried by the spiral banding, the wood acting as a beam in carrying the pressure over the spaces between the banding. The principal duty required of the shell is to stand as a neutral material against the chemical action of the water or anything which it holds in solution, and as a heat insulator to protect water from freezing. In practice it amounts to an iron, steel or bronze pipe (according to material used in banding), with a lining of wood. As the wood is a non-conductor of heat it is able to resist the action of frost on the water to a marked degree, and in case of an exposure to a temperature sufficient to freeze water in the pipe the elasticity of the pipe is enough to save it from permanent or serious damage. In December, 1892, at Norway, in the Upper Peninsula of Michigan, the writer was finishing the construction of a new waterworks system in which all of the mains were improved Wyckoff pipe. On a line of six-inch pipe about half a mile long, the

earth excavated from the trench became frozen by a sudden dropping of temperature so that it had to be picked before it could be back filled. The chunks of frozen earth could not permit much settlement over the pipe, and cold air had very little difficulty in reaching the pipe. The city officials were anxious to have water let into the entire system for fire protection as soon as construction was finished. Water was let in. Cold weather, at very low temperature even for that cold climate, continued for several weeks, with the result that no water was obtained from that half mile of pipe until the following May on account of the water in the main having been frozen. Soon after it thawed a pressure of 170 pounds per square inch was placed upon the line without developing any leaks, and the line has given good service since.

JOINTS.

As stated at the beginning of this paper, there are two ways of making the joints. The ordinary mortise and tenon joints for low pressure pipe will hardly need any comments here, but the thimble joints for high pressure pipe are a matter of interest. The thimbles in pipe 5 inches in diameter and larger are eight inches long and approximately half as thick as the wood shell of the pipe. They are made of dry seasoned white pine with an inside diameter the same as that of the pipe, and an outside diameter one-eighth of an inch larger than the diameter of the mortise in the end of the pipe. When these thimbles are driven into the mortises, they are, of course, a very tight fit to begin with, but when water is let in and the pipe and thimbles become water soaked, the joints become so tight as to hold the water with high pressure in gravity and direct pumping water works systems. The mortises in each end of the pipe are half the length of the thimbles, and half of the thickness of the shell is bored away in forming it. When the pipe is laid it has the same inside and outside diameters continuously.

The thimbles are driven into one end of the pipe before leaving the factory. Before driving the thimble into the pipe, both mortises are painted with residium oil, and the protruding portion of the thimble is also painted on the outside with it to lubricate the surfaces to facilitate the work of driving them together. The joint is well illustrated in the cut. Thimbles are slightly rounded off at the ends to allow a slight entrance into the mortise before driving.



THE ACHEAT CO.-CIR.

LAYING.

After the trench has been prepared the pipe is lowered by hand. Two men are kept in the trench all the time, one of whom takes hold of and lowers the end of the pipe containing the thimble. He then carefully brushes off the thimble with a small hand broom, and sweeps out the mortise which the thimble is about to enter to make sure that nothing will be present to scratch or mar the joint. After lowering and entering several lengths of pipe—if laying the smaller sizes—he places a driving block in the mortise of the last pipe lowered to receive the blows of the ram which drive the lengths of pipe together. The other man lowers the end of the pipe with the open mortise, and helps to handle it while the thimble is being entered, and operates on the ram.

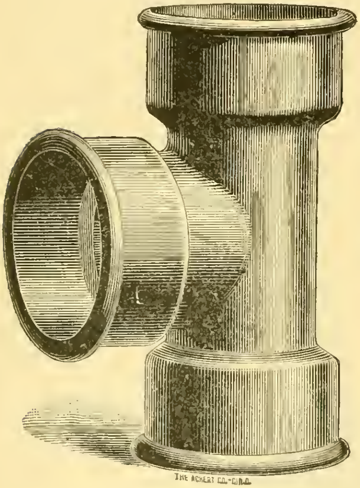
The driving block is made of oak or some hard wood, turned so that one end of it sets squarely against the shoulder of the shell at the inner end of the mortise. The other end of the driving block is rounding, and is struck by the ram. Iron bands are driven on the driving block to keep it from splitting. A handle of $1\frac{1}{2}$-inch gas pipe, $2\frac{1}{2}$ to 3 feet long, enters a hole bored in the centre of the block at an angle of 45 degrees. The ram should be made of

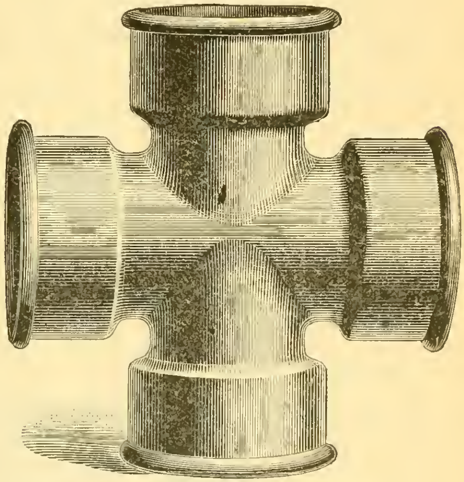
a block of hard wood 8 inches or 10 inches in diameter, and about 4½ feet long. Both ends should be banded with iron rings. A handle three feet long making an angle of 20 degrees is fastened to one end, and a staple and bull ring put in the middle. The ram is suspended by a rope tied to the bull ring, and passing around a long pole or 4″x4″ stick thrown across the top of the trench, and its adjustments are governed and the rope held in position by a workman. Five or six blows of the ram are usually enough to drive up a joint. It is practical to drive six or eight lengths of pipe 6″ in diameter or smaller at one time, and two or three lengths of eight and ten-inch pipe at one time, but it is better to drive one length of the larger pipe at a time. By driving several lengths together at once considerable time and expense can be saved. The only difficulty encountered is when the sides of the trench have a tendency to cave. By having the blows for a number of lengths struck at one place, earth from the sides of the bank is likely to be jarred down. But if only one length is driven at a time this trouble can be avoided. A considerable quantity of Wyckoff pipe has been laid by using a heavy sledge to strike against the driving block and good work accomplished, but a heavier blow can be struck with a ram with less exertion from a workman, and will not tire him out like handling a heavy sledge. Besides, this pipe can be laid much faster and cheaper by using the ram.

In driving the pipe together the ends should be brought up tight, but in making slight deflections in alignment or grade, a small gap or opening on one side of a joint can be left without detriment to the work.

As there is no lead or packing used in making a joint, it is not necessary to have a dry trench to work in. The only limit to the quantity of water in a trench is that there should not be enough to float the pipe. If there is danger of enough water getting into the trench to float the pipe, then the trench should be back filled enough to hold it down or anchor it. Wyckoff pipe can be laid through marshes, swamps and wet ground with nearly as much facility as through dry ground. Of course, no bell holes are required. Care should be taken to see that hot pitch is placed on parts where the coating may have been chafed off in transportation or handling. This is not extensive in any event, but it is a point which needs watching. Four men will constitute a pipe laying

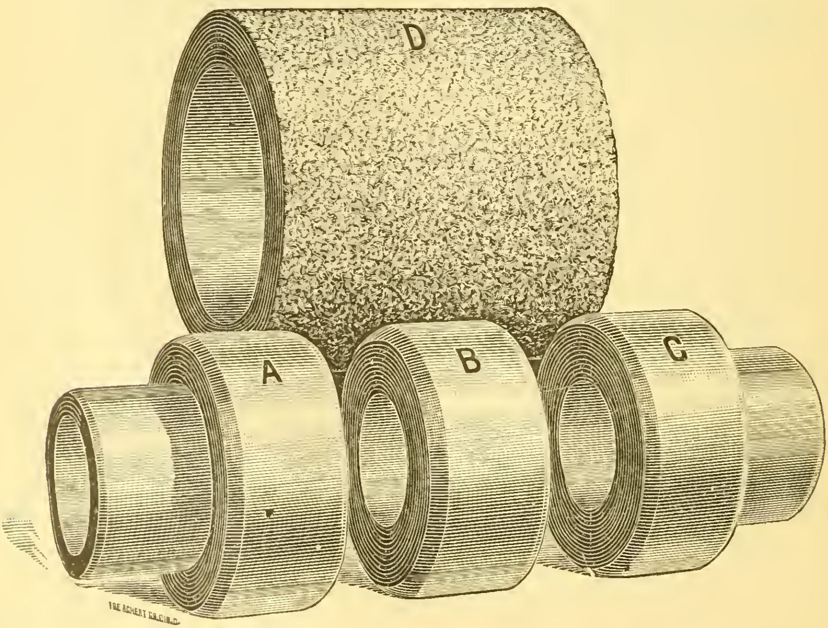
gang for pipe 6 inches or smaller, and five or six men for larger sizes. Common laborers of ordinary intelligence will make good pipe layers with half a day's experience to guide them. In laying pipe in a large system it is a good plan to have a competent foreman to handle the pipe crew, but in a small system one foreman can easily handle the whole work. In low pressure pipe systems, the tees and crosses are made of wood, but for the high pressure systems short cast iron tees and crosses are used. The bells of these spe-





cials are bored the same diameter as the mortises in the pipe. The entrances of these mortises are slightly rounded so that the metal will not cut the thimbles in driving. Any standard make of valve or hydrant can be used by boring the bells in a similar manner. Plugs are turned to fit mortises of pipe which are used to close up dead ends or unused branches of specials. Dead ends are braced against large stone, timber or plank, according to the nature of the ground and convenience of materials. Tees and hydrants are braced in the same way. In connecting two parts of a pipe line together, several methods are practiced. One method is to lay the two parts of the line to a point within fifty or seventy-five feet of each other, then the exact distance to be filled with pipe is measured. After selecting the pipe to fill the space, lay all pipe in the usual manner, leaving the last mortise and thimble uncoupled. Then the two ends of the pipe line are raised four or five feet until

the thimble will enter the mortise, when it is gradually lowered and the weight of the pipe in lowering forces the thimble into the mortise, so that when completed it has the same appearance as pipe that has been driven together. Another method is to bring three lines together to a cross or tee. The side of the trench for forty feet each side of the special is dug back gradually until the thimble will enter the bell of the special. The pipe and special are worked back into line, bringing the end of the joints close together, and at the same time connecting with the line which is to branch from the tee. Another method is to bring the two ends of pipe to be connected within a foot of each other and connect with a sleeve. The sleeve has an internal diameter slightly larger than the outside diameter of the pipe, so that it can be easily slipped over the pipe. The small end of the reducers fit into the mortises of the pipe, and the large ends fit the inside of the sleeve. A filling piece, termed a "Dutchman," is four inches long, having the same inside diameter as the pipe it connects, and the outside diameter the same as the internal diameter of the sleeve. The sleeve itself is a straight piece of pipe shell without mortises. When the reducers and "Dutchman" have been put in place the sleeve is driven over them.



In the cut A and C are reducers, B the "Dutchman," and D the sleeve. The lengths of the large part of reducers are four inches, making the space between pipe just twelve inches, but an adjustment for other measurements can be made by sawing the "Dutchman" for shorter spaces or putting in a piece from another "Dutchman" for a space longer than twelve inches. All of these connections are very simple and can be made quickly and, "like swallowing, more easily done than told." For inserting tees, crosses or valves in established lines of pipes, the length of pipe to be replaced is taken out by sawing through the thimbles at each end of the pipe, and putting in a new length of pipe, sleeve and special to just fill the space of the pipe removed.

In reducing from any diameter of main to a smaller one, reducers made like those shown in the cut are used. It is not good practice to reduce more than two inches at a time. In an ordinary water works system with fair material such as sand, clay or loam to trench through, a gang of forty laborers and one team of horses will trench, lay 1,000 to 1,200 feet of pipe, specials and hydrants, and refill the trenches in a day.

SIZES.

The standard length of the pipe is eight feet and internal diameters run from two inches to 17 inches. The following table gives standard outside diameters of finished pipe.

Bore.	Outside Diam.	Bore.	Outside Diam.	Bore.	Outside Diam.
2	4½	5 Inch.	9 Inch.	12 Inch.	17 Inch.
3	6¼	6 "	10¼ "	14 "	19½ "
4	7¼	8 "	12½ "	16 "	21½ "
		10 "	14½ "	17 "	22½ "

Many lengths shorter than eight feet are made, which by leaving slight gaps or openings on the side of the joint in laying enables one to lay a pipe line over very rough ground and will save considerable expense in making cuts to get an even grade. For making deflections or curves in a pipe line "curved" pipe is made, which is the same as the straight Wyckoff pipe, except that the ends are mitred and the mortises bored at right angles to the mitred end. A curve of any desired radius can be laid by the use of this "curved" pipe, and by using it with the straight, a line can be laid over exceedingly rough ground, saving a great deal of expense for grading, which would otherwise have to be done.

TAPS FOR SERVICE PIPES.

In tapping Wyckoff mains for service pipe, a hole is bored into the shell of the pipe between the banding with an extension bit, to a point within about a quarter of an inch of the inside of the shell. A brass corporation cock with a long coarse thread is then screwed into the shell. The valve in the corporation cock is opened and the hole in the shell completed with a smaller bit. As the bit is withdrawn the augur chips are forced out with the pressure. A workman will soon become so expert in making these connections that he will not lose a quart of water from the main in the whole operation, and do all the work without shutting off the main, and without the use of any tools other than a brace and bit and an ordinary pipe wrench.

PROTECTION OF BANDING.

The heavy coating of pitch put on the outside of the pipe, protects the outside of the banding from being corroded by anything in the soil. The close contact of the band with the wood shell protects the underside. The coating averages one-eigth of an inch in thickness.

FRICTION AND WEAR.

When the diameters of the Wyckoff water pipe are well proportioned for the service it is to be placed under there is nothing remarkable about either the friction or the wear of it. The inside surface of the pipe is not quite as smooth as a planed surface of a board, but it is very much smoother than a sawed surface. After the pipe has been used a few years, any small particles that occasionally are left clinging to the surface are washed away and the surface becomes smoother.

In the summer of 1896 the writer made a careful measurement of the velocity of flow of water through a new four-inch Wyckoff pipe line, and found it corresponded with results obtained by Poncelet's Modification of Eytelwein's formula :

$$V = 48 \sqrt{\frac{DH}{L + 54 D}}$$

There is no doubt but what better results are obtained after the pipe is used a few years. The writer considers it safe practice

to use .011 for the coefficient of roughness for n for new Wyckoff pipe and .01 to .0105 for n for Wyckoff pipe after several years' use when making calculations by Kutter's formula. Numerous opportunities for observing the wear of Wyckoff pipe have been afforded the writer, but only in one case had any apparent wear taken place. That was in a six-inch pipe which had been in use between ten and eleven years, and the diameter had been increased about one-quarter of an inch. But this line had been very much overworked, and a twenty-inch pipe was substituted for it. This six-inch Wyckoff pipe which was taken up was relaid in other parts of the town, and has given good service since. No incrustations nor barnacles, nor anything of that kind has been observed clinging to the interior of the pipe.

ELECTROLYSIS.

The writer has been in a position to hear of any injury to improved Wyckoff pipe by the action of electrolysis, and has yet to hear of the first case of damage to it from that source. A great deal of pipe has been laid in the vicinity of electric railroads with very poor bonding, and in some places where rail bonds have been entirely severed. The heavy coating of pitch is a good insulator for the metallic banding. There is a space of one inch between the bands at the end of the pipe, so that there is a break in the metallic circuit on each section of pipe. Electricians give it as their opinion that a current will find a better conductor in the earth than in the wood shell and follow the earth rather than the pipe.

At West Bay City, Michigan, about three years ago, electrolysis destroyed a four-inch line of cast-iron pipe and a lot of lead service pipes. A line of improved Wyckoff main was put in to replace the cast iron pipe, and a lot of two-inch Wyckoff pipe was laid for service pipe, and has not been affected.

It has been recommended that cities bothered by electrolysis put in sections of improved Wyckoff pipe to break the metallic connection furnished to electric currents by cast iron pipe.

GENERAL REMARKS.

It is a common practice where street grades are lowered to disconnect service pipes at the corporation cocks and fasten the hydrants to connecting tees with two $\frac{3}{4}''$ or $\frac{7}{8}''$ rods and lower the

whole length of improved Wyckoff pipe while the ordinary pressure of the system remains on the pipe, and without causing joints to leak. In lowering the pipe a trench is dug down by the side of the pipe to the depth it is desired to place it. The pipe is braced occasionally to keep it from slipping sideways in uncertain ground, but in firm ground such precaution is unnecessary. After finishing the trench at the side of the pipe the ground is dug out from the under side of it, leaving supports of earth to hold it every 8 or 10 feet. Any kind of blocking may be placed between these supports that will permit the removal of one or two inches of thicknesses at a time. Small pieces of boards and plank and old brick make excellent blocking. The earth and block supports are alternately worked down an inch or two at a time until the pipe lays in the bottom of the trench.

In laying pipe for a gravity line through wild country the pipe need only be buried deep enough to protect it from fire, falling timber, etc.

Connections of improved Wyckoff pipe can be made with cast iron pipe systems by having the bell of the valve bored on one end to fit the thimble of the Wyckoff pipe and a regular cast iron pipe connection on the other end of the valve. In a like manner connections can be made at tees, crosses or with a straightway casting having one bell bored for the Wyckoff pipe and the other for cast iron pipe. A considerable quantity of Wyckoff pipe is used outside of water works systems. Coal miners make extensive use of it for handling sulphur water that is so common in coal mines. It is used about other mines for handling mineral waters that eat out iron pipes for both suction and discharge pipe.

Last spring a line of it was put in Chicago to carry hot soup from one of the packing houses to a glue factory. Another line about two miles long having five-inch internal diameter and a four-inch shell is used by a Canadian distillery to carry hot slops from the distillery to cattle feeding sheds. This line has been in use about eighteen years. A line about eleven miles long was used 15 years to carry brine in Eastern Michigan. It is used in bleacheries, sulphite fibre works and other works where water containing chemicals are to be handled. The various state and United States fisheries also make large use of it.

EXTENT OF USE.

The writer has not access to records at the time of writing this paper, but would give as an off hand estimate of the amount of improved Wyckoff pipe in use as 1,500 miles. The total mileage of the pipe having wooden shells such as stave pipe, etc., will greatly exceed this mileage. The writer knows of but three systems in New England, those being at Antrim, Belmont and Penacook, all in the state of New Hampshire. There are a number of these works in Pennsylvania, New York, the Middle and Western States and Territories. Michigan probably has a greater mileage than any other one state. Some of the largest systems being Bay City, Michigan, containing about 35 miles of improved Wyckoff pipe, North Tonawanda, N. Y., 31 miles, with Tonawanda, N. Y., an adjoining municipality, with 14 miles more, Ishpenning, Michigan, 26 miles, Ionia, Michigan, 18 miles, DuBois, Pa., 16 miles. In Denver, Colorado, there is a considerable quantity of the pipe used and the entire system at Cripple Creek, Colo., is of improved Wyckoff pipe, but the writer does not remember the exact mileage in use in these places. There are a large number of municipal water works systems using from three to twelve miles of this pipe. It is a notable fact that the iron mining towns of Ishpenning, Negaunee and Norway, Michigan, make large use of improved Wyckoff pipe in their systems.

COST.

The price of the pipe has varied as other materials varied. At the present time the installation of a distributing system of improved Wyckoff mains will run as much as 25 per cent less than the cost of a system using cast iron mains, and at other points they will cost as much as a system of cast iron pipe, the difference in price depending very largely on freight rates.

SALT WATER FIRE SYSTEM OF BOSTON.

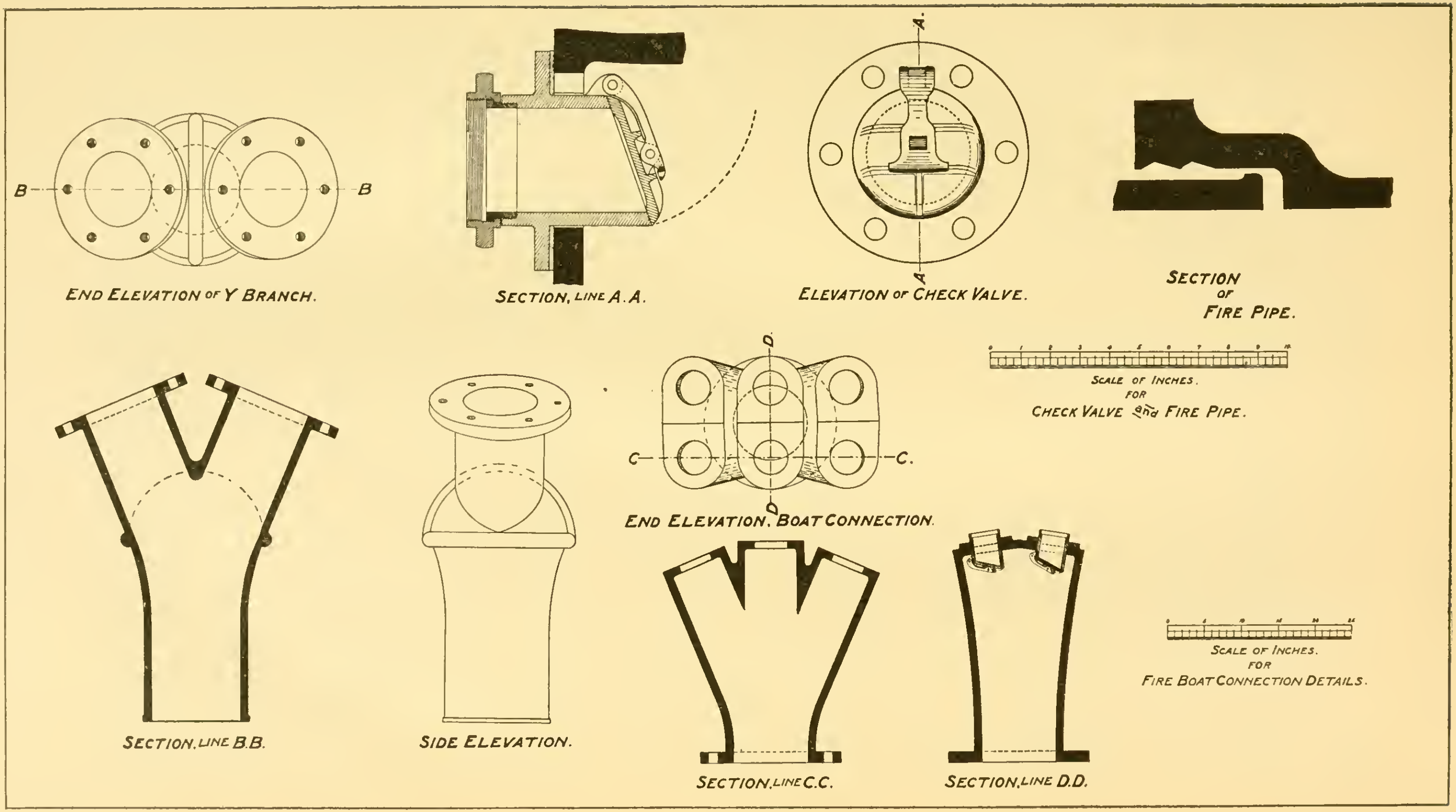
BY FRANK A. MC INNES.

[*Read January 11, 1899.*]

Two fire boats, each of a nominal capacity of 6,000 gallons per minute, constitute the "heavy artillery" of the Boston Fire Department. To extend the radius of action of these boats, making their power available for extinguishing fires at points in the city at a distance from the immediate water front, is the mission of the salt water fire system recently established. Its description is as follows:

A 12-inch cast iron pipe extends from deep water at Central Wharf, through Central, Exchange and Devonshire Streets, Post Office Square and Congress Street, to deep water at Congress Street bridge, a distance of about 5,000 feet. At Central Wharf the line divides into two 10-inch pipes, each of which terminates at a special casting or "boat connection" fitted with six $3\frac{1}{2}$-inch outlets, to which hose can be directly attached. Each outlet has a valve opening inward. One or both boats can connect with the pipe, using all the 12 outlets provided, or as many of them as are desired. The lengths of $3\frac{1}{2}$-inch hose used between boat and "connection" vary from 15 to 30 feet. A similar boat connection is designed for the end of the pipe at Congress Street bridge, but other construction at that point has delayed its completion.

Hydrants are established along the line about 300 feet apart, each gated off from the main pipe; valves set on the main line make it possible to shut off different sections if the need arises, and branches at different points provide for future extension. The system is designed to operate with a maximum pressure, at the Fire Boat, of 200 pounds. Near each end of the line 6-inch relief valves are placed, designed to open in case of undue pressure. Manholes or boxes surrounding valves and hydrants are of masonry. Electrical connection is provided from each hydrant to


END ELEVATION OF Y BRANCH.
SECTION, LINE A.A.
ELEVATION OF CHECK VALVE.
SECTION OF FIRE PIPE.
SCALE OF INCHES. FOR CHECK VALVE and FIRE PIPE.
END ELEVATION. BOAT CONNECTION.
SECTION. LINE B.B.
SIDE ELEVATION.
SECTION. LINE C.C.
SECTION. LINE D.D.
SCALE OF INCHES. FOR FIRE BOAT CONNECTION DETAILS.

fire boat. The main pipe is kept full of water from a 12-inch check valve at Central Wharf to a similar valve at Congress Street bridge, pressure being maintained up to check valves and to foot valves of hydrants and the absence of air assured by means of a one-inch pipe leading from main pipe to a tank in the Post Office building, the tank being supplied directly from the city mains. Two check valves set in this "connection" guard against "too much salt," by closing when fire pressure exceeds the ordinary city pressure. At each end of the line a short length of pipe beyond the limit of solid ground is necessarily exposed and must be maintained empty in cold weather. The system is always ready for use and no time need be lost in preliminary action; in actual operation the fire boat begins to pump slowly just as soon as its first hose connection is made with the pipe, expelling the air from the empty end through an air cock provided for the purpose; when the necessary number of hose connections are made the air is entirely driven out and the boat can "play away." A second boat can connect at any later time and get to work at once.

In Cleveland, Milwaukee, Detroit and Buffalo, systems largely similar have been in successful operation for several years; in each case, at least during cold weather, the pipes are empty when not in actual service; this method permits shallow excavation by eliminating the factor of frost and probably prolongs, to some extent, the life of the pipe. The disadvantages are loss of time in filling the line and the possibility of damage from imprisoned air in the operation of filling. The method adopted in Boston of keeping the pipe always full, while it seemed the part of wisdom on its own merits, was the only feasible one, at a cost at all reasonable. The topography of the streets and the obstructions under their surface made uniform gradients practically impossible. An alignment free from sharp bends, either vertical or horizontal, was insisted upon and obtained with difficulty. At many points the way was absolutely blocked within six feet of the surface by water pipes, gas pipes, sewer connections, fire reservoirs, conduits of all kinds and shapes, etc., etc., and at times the excavation was in brick and concrete rather than in earth. The result was a trench more than seven feet in depth. Great care was exercised in making the lead joints and all points of possible weakness, such as hydrant pots, caps, branches, etc., were treated in a conservative manner and securely

fastened directly from the main pipe by means of tie-rods and collars. Care in these small details had its reward; when the line was tested, under fire pressure, everything held securely and there is no leakage, at least, not enough to be indicated by a one-inch meter on the pipe leading to tank in Post Office. The work was done by men from the Boston Water Department.

It was necessary to meet one condition, concerning which little exact data or in fact data of any kind was on record, viz., the use of salt water in the pipes. Boston is the pioneer in this field as far as fire systems are concerned. The problem was complicated when it was decided to maintain the line always full of water. One fact seemed well established, viz., that iron, composition and salt water would prove a disastrous combination if situated as they would necessarily be were the ordinary valve or hydrant adopted; a galvanic action would undoubtedly result at the expense of the iron; the valves were therefore made of solid composition, fitted with flanged ends, and were insulated from the adjoining pipes by heavy washers or rings of pure rubber; the hydrants are empty when not in use, and the only precautions taken were to separate the composition valve seat from the iron hydrant pot by a lead joint, and to protect the end of the main valve stem (of Norway iron) by a composition cap, making a water tight joint with the bottom of the rubber foot valve.

The use of cast iron in the pipe line was, in a sense, the choice of evils, as either of the other available metals, steel or wrought iron, are much more quickly affected by salt water. A number of cases in the neighborhood of Boston where salt water was pumped through cast iron pipes were investigated, the history of water pipes subjected to salt water on the outside for many years was studied, and all available data considered. The conclusion arrived at was that while cast iron pipe, used for conveying salt water, would suffer more from corrosion than if fresh water were flowing in it, yet it could be depended upon for a number of years. No case was found where a pipe had failed where the question involved only cast iron and salt water, and some were investigated where these conditions had existed for more than twenty years. Under the conditions, with the salt water quiet when the system is not in use, and with pipe of unusually heavy section, it seems very possible that conditions other than the salt water flowing through the

pipe might limit its life. That deadly foe to water pipes, electrolysis, is a worthy rival in the race, and particular conditions of surrounding soil may prove disastrous. If examination shows that the pipe is being quickly affected by the salt water, it will be possible to fill the system with fresh water after service, and to so maintain it until it is next used.

The pipe section used is of the general B. W. W. pattern. An innovation was made in the introduction of two grooves or lead scores in the bell; they were designed as an aid towards ensuring tight joints in caulking, and also add to the strength of the joint; thirty-five to forty pounds of lead were used in each joint. The pipe is unusually heavy, being one inch thick; about one-tenth of an inch was added to the thickness calculated from the ordinary factors in deference to the severe conditions expected; it weighs 142 pounds per foot, or 1704 pounds per length laying twelve feet. Each pipe was subjected to a water pressure at the foundry of 500 pounds per square inch. The coating was made by the well-known method of immersion in a bath of distilled coal tar, particular care being taken to see that the operation was thoroughly performed.

The Bachelder hydrant (so called from the name of the inventor and patentee, Mr. Bachelder, master mechanic of the Boston Water Department), somewhat modified to meet the particular conditions, was adopted. It is a post hydrant, unusually heavy throughout, with three 3-inch outlets, each controlled by an independent valve. The waste is positive, and is operated by a long-handled wrench from the street surface. Through the side of the hydrant a one-inch hole is cored out to carry the electric cable, terminating at the top in a recess which forms a signal box. In this way means of electrical communication was afforded in the hydrant itself, and the need of an independent pillar and signal box was avoided.

The electrical signal service was installed by the Fire Department.

A three-inch, cement-lined wrought iron duct, protected on the outside by concrete, and laid in the main pipe trench, carries a five conductor cable.

A junction, made with a cable belonging to the regular fire alarm service, establishes communication with headquarters, and makes this circuit a part of the fire alarm system of the city.

It is afforded all the appliances, and is subject to the same

SALT WATER FIRE PIPE TEST

At Post Office Square, Boston, Mass.

November 13, 1898.

Experiment Began.	Experiment Ended.	Elapsed Time.	LINE NO. 1.					LINE NO. 2.					LINE NO. 3.					LINE NO. 4.					LINE NO. 5.					LINE NO. 6.					Total Discharge Per Minute.	Pressure at Hydrant Outlets, Line No. 1.	Loss of Pressure in Hose, Line No. 1, corrected.	Loss of Pressure per 100' under given discharge.	REMARKS.
			Length of Hose.	Diam. of Hose.	Diam. of Nozzle.	Indicated Pressure at Nozzle.	Discharge Per Minute.	Length of Hose.	Diam. of Hose.	Diam. of Nozzle.	Indicated Pressure at Nozzle.	Discharge Per Minute.	Length of Hose.	Diam. of Hose.	Diam. of Nozzle.	Indicated Pressure at Nozzle.	Discharge Per Minute.	Length of Hose.	Diam. of Hose.	Diam. of Nozzle.	Indicated Pressure at Nozzle.	Discharge Per Minute.	Length of Hose.	Diam. of Hose.	Diam. of Nozzle.		Discharge Per Minute (Approx)	Length of Hose.	Diam. of Hose.	Diam. of Nozzle.		Discharge per Minute (Approx)					
H. M. S	H. M. S	M. S.	Ft.	In.	In.	Lbs.	Gal.	Ft.	In.	In.	Lbs.	Gal.	Ft.	In.	In.	Lbs.	Gal.	Ft.	In.	In.	Lbs.	Gal.	Ft.	In.	In.			Ft.	In.	In.			Gals.	Lbs.	Lbs.	Lbs.	
10-27-30			150	3	1¾			150	3	1⅝			150	3	1¾																						Pumps started at 10-27-30.
10-26-00	10-28-30	0-30	"	"	"	44.3	627		"	"	45.3	617		"	"	44.6	611																1855	109.0	63.7	43	
10-28-30	10-29-00	0-30	"	"	"	50.0	668	Into Eastman Set.	"	"	51.8	660	Into Eastman Set.	"	"	50.3	651																1979	126.0	75.0	50	
10-29-00	10-30-00	1-00	"	"	"	56 6	703		"	"	56.1	687		"	"	55.0	080																2070	134.6	77.9	52	
10-30-00	10-31-00	1-00	"	"	"	57.7	716		"	"	58.1	699		"	"	57.0	693																2108	138.6	79.8	53	
10-31-00	10-31-30	0-30																																			Shut down.
10-31-30	10-32-00	0-30	150	3	1⅝	49.5	664	150	3	1⅝	51.3	657	150	3	1¾	50.0	648																1969				
10-32-00	10-32-30	0-30	"	"	"	54.0	693	"	"	"	55.3	682	"	"	"	54.5	677																2052				
10-32 30	10-33-30	1-00	"	"	"	57.0	712	"	"	"	58.3	700	"	"	"	57.0	693																2105				
10-33-30	10-40-00	6-30	"	"	"	58.8	724	"	"	"	59.6	708	"	"	"	57.6	696																2128				
10-40-00	10-41-30	1-30	"	"	"	60.0	732	"	"	"	61.8	721	"	"	"	58.1	699																2152				Shut down at 10-41-30.
10-41-30	11-11-30																																				Changing Hose Lines and Nozzles.
11-11-30			300	3	1¼			300	3	1¼			300	3	1¼			300	3	1¼			300	3	1¼			300	3	1¼							Pumps started at 11-11-30.
11-12-00	11-13-00	1-00	"	"	"	75.6	400	"	"	"	70.7	387	"	"	"	65.0	371	"	"	"	72.6	392	"	"			388	"	"			388	2926	128.0	61.6	17.2	
11-13-00	11-14-00	1-00	"	"	"	86.8	429	"	"	"	82.0	417	"	"	"	85.2	425	"	"	"	84.4	423	"	"			424	"	"			424	2542	140.0	52.2	17.4	
11-14-00	11-16-00	1-00	"	"	"	93.5	445	"	"	"	88.8	434	"	"	"	93.9	446	"	"	"	93.0	444	"	"			442	"	"			442	2653	147.7	63.2	17.7	
11-15-00	11-17-00	2-00	"	"	"	100.0	459	"	"	"	94 8	448	"	"	"	101.3	463	"	"	"	98.7	457	"	"			457	"	"			457	2741	152.8	52.8	17.6	
11-17-00	11-18-30	1-30	"	"	"	102.2	466	"	"	"	97.8	456	"	"	"	104.8	471	"	"	"	101.3	463	"	"			464	"	"			464	2782	157.0	63.8	17.9	
11-18-30	11-19-30	1-00	"	"	"	104.4	470	"	"	"	105.2	472	"	"	"	109.1	481																				
11-19-30	11 21-00	1-30						"	"	"	111.0	485	"	"	"	120.9	606																				Shut down at 11-21-00.
11-21-00	11-35-30																																	Pr. at Hyd Outlets, P.O Square.	Loss in Lines, P. O. Sq. Hyd. Corrected		Changing Nozzles.
11-35-30			300	3		Siamesed		300	3	2			300	3		Siamesed		300	3	2			300	3		Siamesed		300	3		Siamesed						Pumps started at 11-35-30.
11-36-00	11-36-30	0-30	"	"		with lines		"	"	"	81.5	1105	"	"		with lines		"	"	"	76.3	1070	"	"		with lines		"	"		with lines		2175	134.5	52.0		
11-36-30	11-38-00	1-30	"	"		2 and 3		"	"	"	89.3	1158	"	"		1 and 2		"	"	"	85.8	1136	"	"		4 and 6		"	"		4 and 5		2293	148.3	68.0		
11-38-00	11-39-00	1-00	"	"		into		"	"	"	91.0	1170	"	"		into		"	"	"	88.5	1153	"	"		into		"	"		into		2323	151.6	59.6		
11-39-00	11-41-30	2-30	"	"		Eastman		"	"	"	94.6	1192	"	"		Eastman		"	"	"	91.6	1173	"	"		Eastman		"	"		Eastman		2365	156.9	61.3		Shut down at 11-41-30.
11-41-30	11-49-00					Set.										Set.										Set.					Set.						Changing Nozzles.
11-49-00			300	3		Siamesed		300	3	2¼			300	3		Siamesed		300	3	2¼			300	3		Siamesed		300	3		Siamesed						Pumps started at 11-49.
11-49-00	11-50-00	1-00	"	"		with lines		"	"	"	46.5	1091	"	"		with lines		"	"	"	56.2	1205	"	"		with lines		"	"		with lines		2296				
11-50-00	11-50-30	0-30	"	"		2 and 3		"	"	"	55.7	1198	"	"		1 and 2		"	"	"	60.2	1247	"	"		4 and 6		"	"		4 and 5		2445	128.5	71 8		
11-50-30	11-51-00	0-30	"	"		into		"	"	"	60.6	1251	"	"		into		"	"	"	65 2	1298	"	"		into		"	"		into		2549	136.7	75.1		
11-51-00	11-52-00	1-00	"	"		Eastman		"	"	"	63.5	1280	"	"		Eastman		"	"	"	66.7	1313	"	"		Eastman		"	"		Eastman		2593	143 0	78.5		
11-52-00	11-54-00	2-00	"	"		Set.		"	"	"	66.0	1305	"	"		Set.		"	"	"	68.6	1331	"	"		Set.		"	"		Set.		2636	148.2	81.2		Shut down et 11-54-00.
11-54-00	11-65 30																																				Changing Nozzles.
11-55-30			300	3		Siamesed		300	3	2½			300	3		Siamesed		900	3	2½			300	3		Siamesed		300	3		Siamesed						Pnmps startad at 11-55-30.
11-56-00	11-66-30	0-30	"	"		with lines		"	"	"	39.6	1317	"	"		with lines		"	"	"			"	"		with lines		"	"		with lines			119.5	78.9		
11-66-30	11-57-30	1-00	"	"		2 and 3		"	"	"	43.8	1383	"	"		1 and 2		"	"	"	47.4	1439	"	"		4 and 6		"	"		4 and 6		2822	128 0	83.2		
11-67-30	11-59-00	1-30	"	"		into		"	"	"	47.6	1442	"	"		into		"	"	"	60.0	1480	"	"		into		"	"		into		2922	140.7	92.1		
11-59-00	12-00-00	1-00	"	"		Eastman Set.		"	"	"	48.8	1462	"	"		Eastman Set.		"	"	"	51.0	1493	"	"		Eastman Set.		"	"		Eastman Set.		2955	146.0	96.2		Shut down at 12-00.

Lines 1, 2, 3, from Hydrant at Post Office Square.
Lines 4, 5, 6, from Hydrant on Congress St., near Milk St.
In the last three sets of experiments, two Eastman Sets were used with three lines from each hydrant. Each Eastman Set includes 16' of 3½" Hose.

In the set of experiments with six 1¼" Nozzles, the discharge from lines 5 and 6 is approximate, as no pressures were taken at the Nozzles, therefore the total discharge for this set of experiments is approximate.

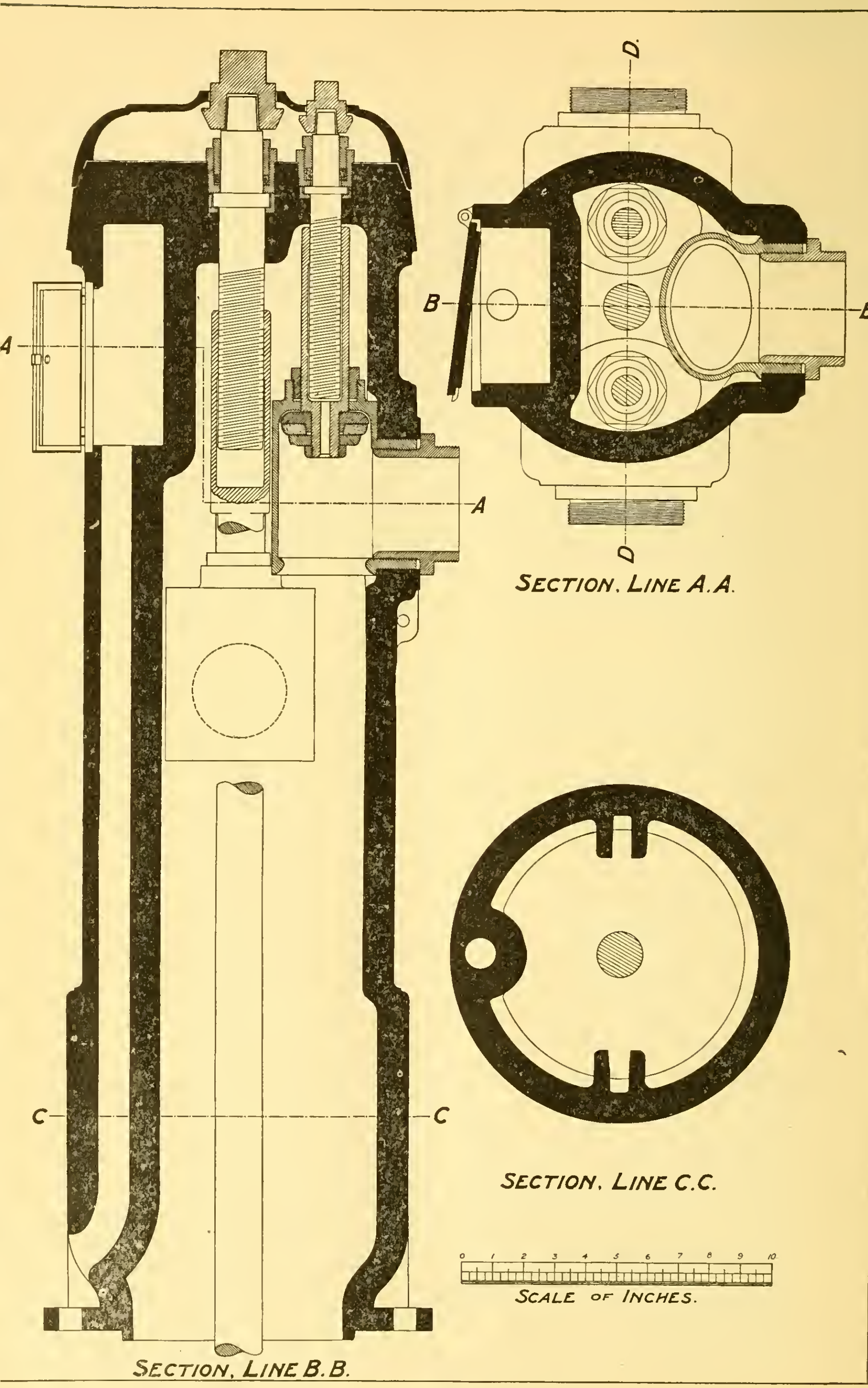
thorough methods of testing and maintenance that are provided for the regular circuits; any trouble occurring, such as a break, short circuit or ground escape, is indicated at the central office, and the fault may be located and repaired with facility. Two of the five conductors in the cable are utilized and a metallic circuit is established, the others being held in reserve for any emergency that may arise.

Each hydrant is equipped with a break key whereby the code signals can be transmitted to the Fire Boat station, where they are sounded on a gong. In addition, portable instruments (consisting of Morse key and sounder), can be connected into circuit by means of jack plugs, at all hydrants and at boat stations; in this way any single hydrant or all the hydrants may be placed in communication not only with the Fire Boat, but with the central office as well, giving a service that extends far beyond the possibilities of a simple signal code.

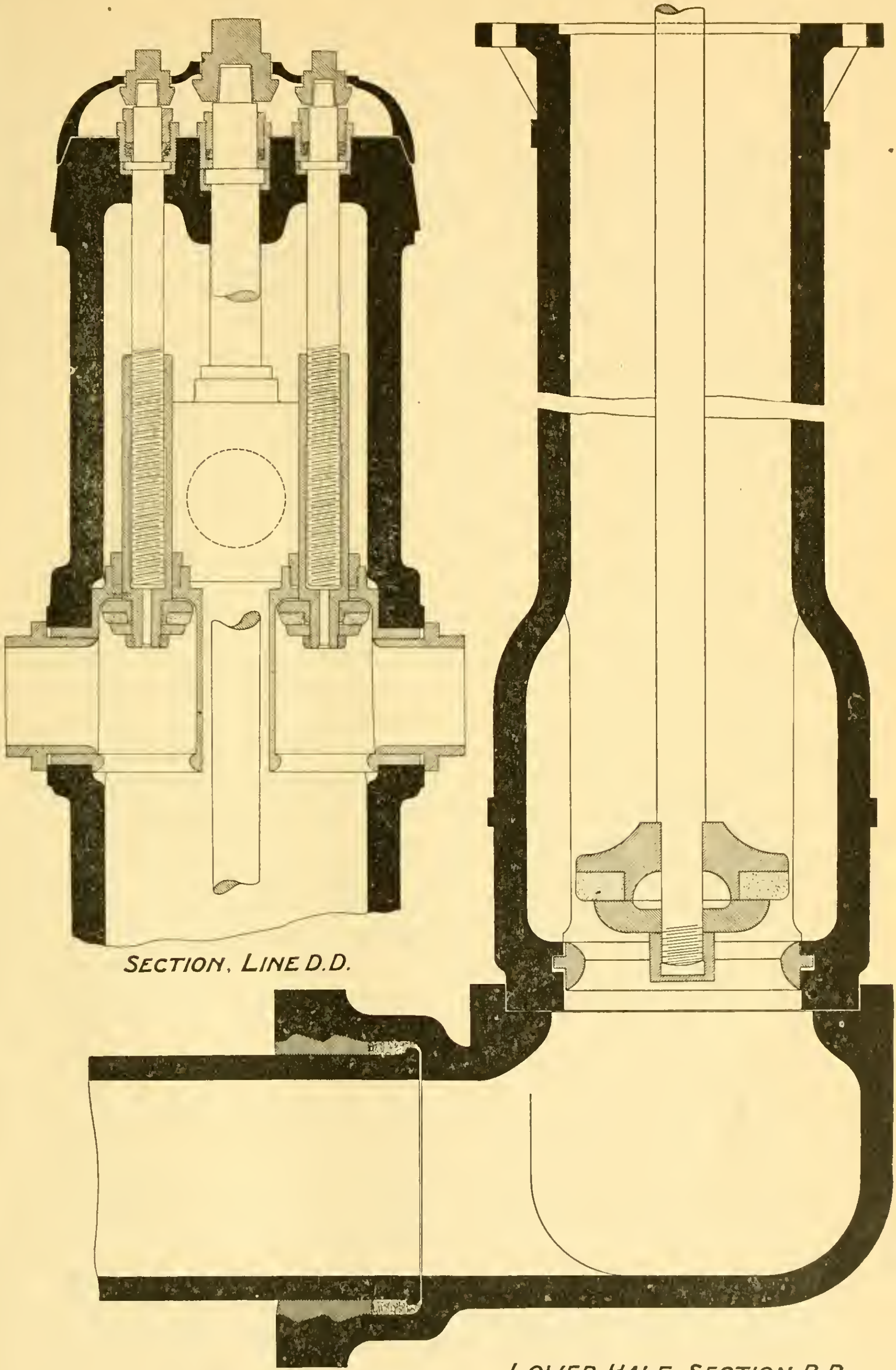
Two of the portable instruments are carried on each boat, one to be used at the boat station, and the other at the hydrants.

This system, as established, must prove in its limited field of action a valuable addition to the other facilities of the city for fighting fire; it is a distinct advance in one important respect, viz., in the application of pumping power in large units, in connection with an unlimited supply of water, ensuring the ability to furnish fire streams of sufficient power at all times, and of unusual size and power when required.

A test of the system recently made at a distance of one-half mile from the water front, with one Fire Boat in service, proved very satisfactory. The following are some of the results obtained: Two streams, each of 1,500 gallons per minute, were played simultaneously through 2½-inch nozzles, with a nozzle pressure of 50 pounds, three lines of 3-inch hose, each 300 feet long, being siamesed for each stream; such a deluge of water would be used to best advantage at long intervals, yet the ability to do work of this kind is invaluable, when the necessity arises very great interests are at stake. Another trial was made with 1¼-inch nozzles, six independent streams being played each through 300 feet of 3-inch hose with a total discharge of 2,760 gallons per minute, the nozzle pressure exceeding 100 pounds, probably too high for best practical results. A third trial was made using three separate lines of 3-inch hose



Details of Bachelder Hydrant.



DETAILS OF BACHELDER HYDRANT.

and $1\frac{3}{4}$-inch nozzles; three very powerful streams were obtained discharging 2,200 gallons per minute with a pressure at the nozzles of 61 pounds.

In the above trials the object was to determine power rather than capacity, and more streams might have been added in each case without falling below a high standard of efficiency.

A separate system of mains for fire protection with permanent pumping power of large capacity promises a much greater degree of economy and efficiency than can be obtained under the conditions that generally exist in our cities, where the power is applied by a large number of comparatively small movable pumps and the mains of the distribution system form the source of water supply.

Much of the water used, in modern practice, during the progress of a serious fire is simply evaporated in the flames, serving no good purpose, the only effective work being often done by a very few streams; this must necessarily be the case, to some extent. Under existing conditions very serious fires or "conflagrations" must occur at times as they have done in the past; the greater the need the more apparent will be the inherent weakness of the present system.

The limit in capacity of the modern movable fire engine must soon be reached, if that point has not already been attained; today propellers or horseless engines are in service weighing nine tons with a nominal capacity of 1,600 gallons per minute. Unfortunately distribution systems have not been designed to bear so heavy a burden with uniform success; points of weakness exist where the mains are old and inadequate and failure must result, at times, unless a large expense is incurred in providing greater capacity.

The movement has been steadily towards greater power since the days of "hand tubs," the nozzles in general use today are twice as large as those in service a few years ago, while the capacity of the largest "steamer" has more than doubled in the past ten years. The advance has been general in the methods of and appliances for fighting fire; this increase in efficiency can be attributed in part to a growing knowledge of the general subject, the result of intelligent study, and in part to the simple necessity of a stronger arm as the buildings grew higher and larger. The end is not yet, for the future will see a great increase in tall buildings, and the majority of fires, in certain sections at least of our cities, will occur in such buildings. Wise legislation may frown upon the extreme "sky

scraper." but future conditions demanding, for safety, more power than is now available, are inevitable. Modern fire-proof construction will improve the conditions, but will not solve the problem.

A city largely surrounded by water, as is the "down town" section of Boston, offers an inviting field for an independent system of fire protection. Some of the essential features of such a system would be:

Connecting mains, in the streets, of moderate size; permanent pumping stations of large capacity, operated perhaps by electricity or compressed air; post hydrants at short intervals; direct connections to standpipes inside of buildings; stand-pipes outside of buildings, both in front and rear, with means for connecting hose at the street level and with outlets at different levels, making them in effect permanent water towers; a moderate pressure always upon the system with the ability to instantly apply full fire pressure; a complete electrical signal service; emergency connections for Fire Boats; the use of existing distribution system as an auxiliary to some extent.

The above conditions would mean the ability to concentrate very large quantities of water at any desired point in the system, and the ability to reach the tops of tall buildings and to uniformly furnish powerful fire streams; a saving of time could be made in the first precious moments of getting to work, which cannot be over-estimated; water could be supplied for street sprinkling and for flushing sewers to great advantage; a very great reduction could be made in the cost of extensions and renewals of the existing distribution systems when the need of providing capacity for fire purposes no longer exists.

THE USE OF STEEL FOR WATER MAINS.

BY L. M. HASTINGS, C. E.

[*Read January 11, 1899.*]

For more than two hundred years, cast iron has been used as a material for the manufacture of water pipes, and, during the latter part of this period, to the practical exclusion of all other materials. In spite of numerous attempts to find a better or cheaper substitute ; wood, cement, lead, glass, wrought iron and steel,—cast iron still holds its supremacy for general use in a water works system. Nothing has yet been discovered or devised which at present warrants any belief in its being displaced for that purpose,—so that no one, either iron founders, mine owners or water works men having large systems of cast iron pipe in charge, need have any feeling of alarm at what may be said regarding the use of steel for water pipes.

While there are situations and circumstances under which steel pipe may be used with advantage, and with a probable saving of money, it is undoubtedly true that the "situations and conditions" in which this material may with advantage be used, are comparatively few. Its field of usefulness is and probably will remain a limited one.

Steel seems best adapted for use :

First. For the larger sizes of mains, say from 24-inch diameter upwards. At about this size the relative cost begins to be in favor of cast iron.

Second. For what may be called leading mains in outlying districts—force mains, and similar work where not likely to be disturbed or tapped.

Third. As conduits in remote regions difficult of access, its lightness and ease of transportation fitting it especially for this use.

Under these conditions the principal advantages in the use of steel are :

First. Economy in first cost. This is in many instances the controlling factor in the case. At the prices which have prevailed for the last six or eight years, quite a substantial saving can usually be made by the use of steel, varying of course, with the size of

the pipe, the market and local conditions, as to its delivery and laying. Thus at Rochester, N. Y., the cost of a 36-inch cast iron pipe in 1892 was $6.21 per foot, and the cost of 38-inch steel pipe $5.84 per foot, a saving of 6 per cent. on the cost of cast iron.

At Cambridge, Mass., in 1895, on comparing bids for 40-inch pipe, it was found that a saving of 31½ per cent. could be made by using steel. (See correction made later.)

At New Bedford, Mass., in 1896, with a 48-inch pipe, an estimated saving of 23 per cent. was made by using steel.

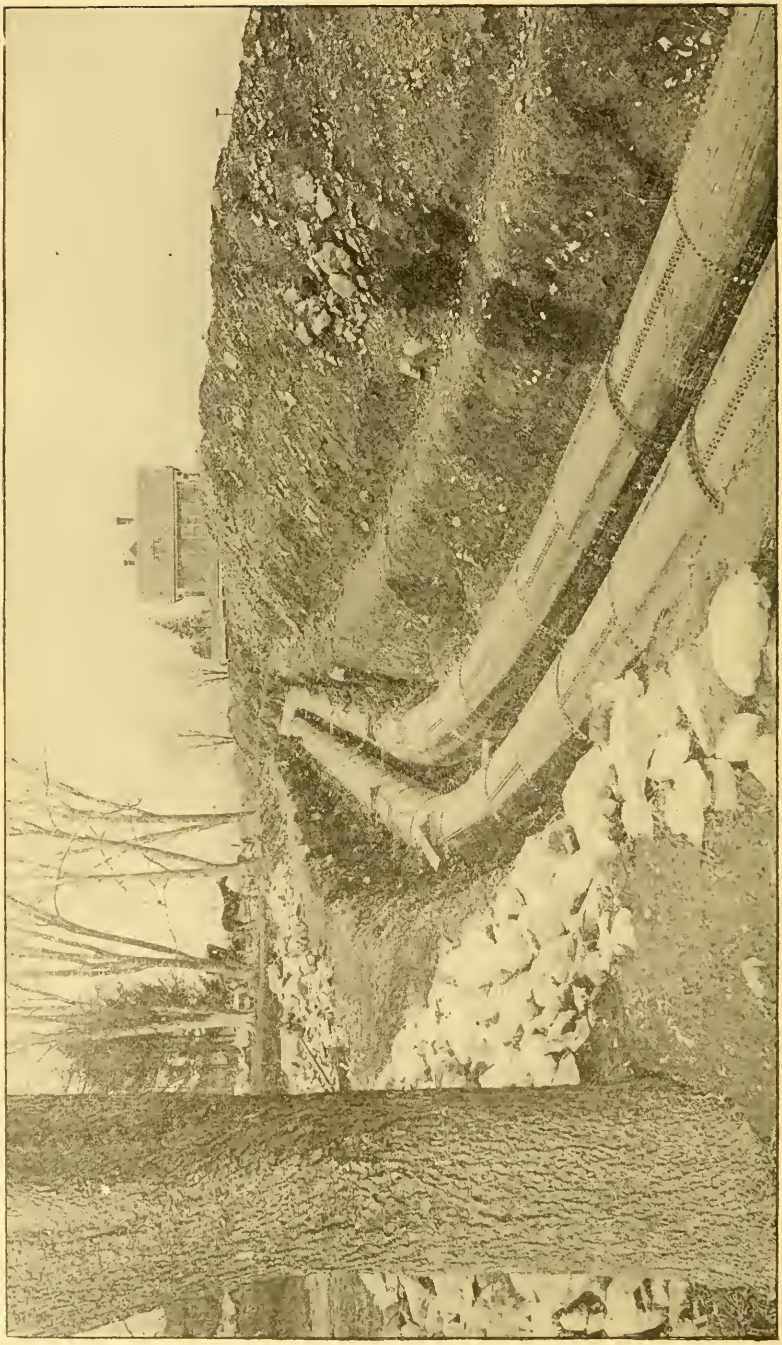
At Minneapolis, Minn., in 1897, with a 50-inch pipe on comparative bids received, a saving of 28 per cent. was made. At Duluth, Minn., in 1897, an estimated saving of 33 per cent. was made by using steel.

Second. Less liability of breakage while in service. Steel plate is undoubtedly a much more reliable material than cast iron to resist tensile strains and the shocks incident to its use in water mains. Being so much more uniform in its texture and tensile strength, with vastly less liability to have flaws and structural defects of a dangerous character,—a much smaller factor of safety can be used and a lighter and more reliable pipe made. It would seem to be practically impossible that, with a properly designed steel pipe, disastrous breaks should occur, such as happened a few years ago in the 48-inch main of the Boston Water Works, on Beacon Street, or last year, 1898, in the 48-inch main in Brooklyn, N. Y., when a large amount of damage was done; or again in St. Louis and Philadelphia in 36-inch mains.

Third. Its adaptability for special situations when the use of cast iron would be attended with risk, or excessive cost. It not infrequently happens that a pipe line is obliged to cross an intervening river, ravine or deep cut, by a bridge or by an inverted syphon, where vibration or excessive pressure would render the use of steel more advisable than that of cast iron. Its use in Ogden, Utah, Minneapolis, Minn., Cambridge, Mass., and Syracuse, N. Y., are illustrations in point.

DISCHARGING CAPACITY.

In comparing the relative costs of steel with cast iron pipe, it is important to know the actual discharging capacity of each kind of pipe of the same diameter. With reference to the discharging capacities of cast iron pipe of varying sizes and under different heads, a great mass of experimental data has been accumulated by



Curved Pipe—Cambridge, Mass.

painstaking experimenters both American and foreign. This great mass of data, however, unless used with the greatest caution and skill will give results so various as to be positively bewildering to the ordinary seeker after reliable facts. It is only by a skillful selection and use of the formula and coefficients derived under conditions similar to that in hand that reliable figures can be obtained.

The remark of the late James C. Duane of New York, that "the degree of accuracy obtainable from any formula is dependent on the more or less (usually less) scientific guess at the value of a modifying coefficient appropriate to each case," seems extremely pertinent in this connection.

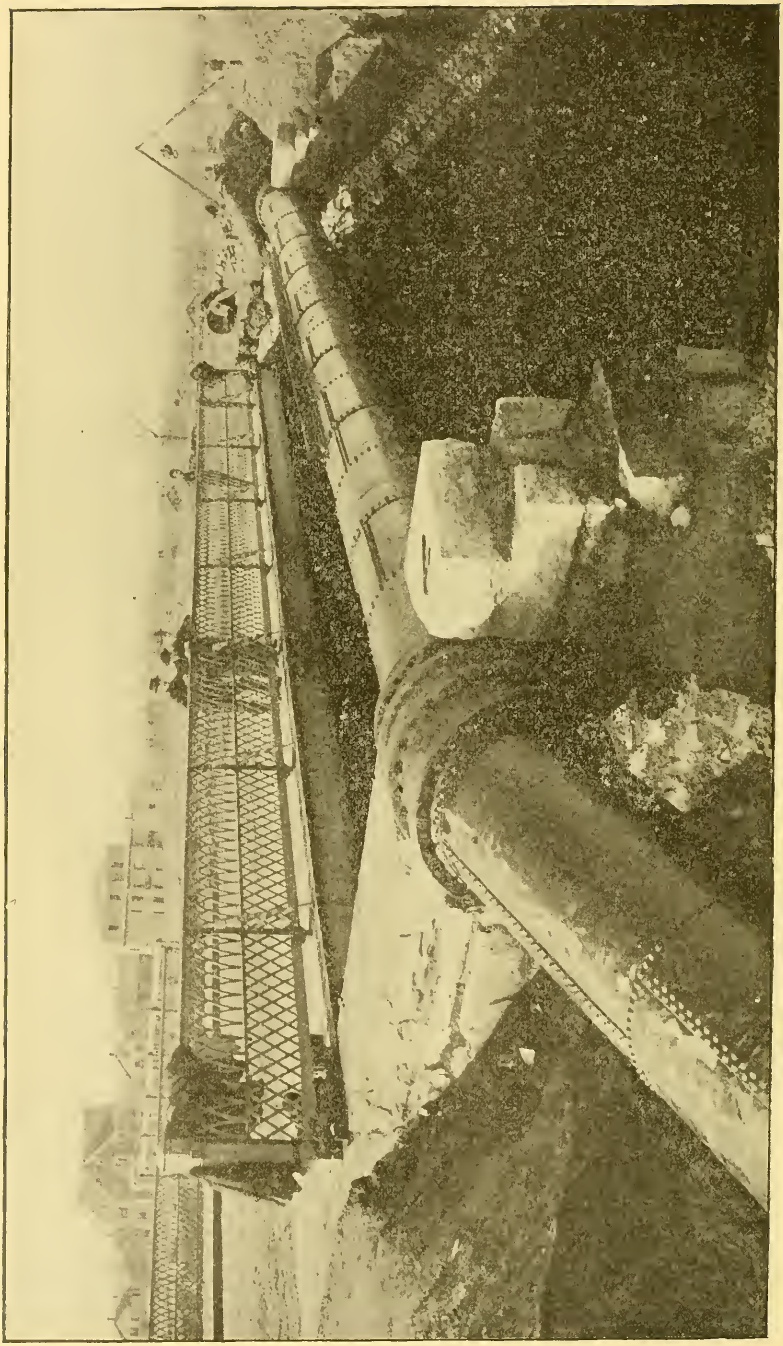
A great many of the formulæ and tables given in text and hand books for finding the delivery of pipes, are for "new, clean and straight" pipe; whereas, in actual practice, these conditions are seldom met with, and in but a few years the conditions as regards smoothness of surface, and consequent delivery, are radically changed.

The gauging test of Mr. Duane on the delivery of a 48-inch pipe in New York is interesting, as illustrating this. The pipe was cast iron, uncoated, and on being tested for delivery soon after laying was found to deliver a quantity equivalent to that computed by the well-known Chezy formula, $V = C\sqrt{R\ S}$, when $C=$ 135.00. Seven years later the same pipe was tested again and found to give a value of $C=96$, a reduction of about 30 per cent. (See Transactions, American Society Civil Engineers, Vol. 1893.)

Substantially the same result has been observed by Mr. FitzGerald in a 48-inch pipe on the line of the Sudbury River Conduit, when value of C as found by Mr. Stearns in 1884 to be from 139.94 to 143.16—in 1896 it was found to be about 108.00. (See Transactions American Society Civil Engineers, Vol. 35, 1896.)

The test made by Mr. Coffin on the friction in force mains as given in Journal of New England Water Works Association, June, 1896, shows in most cases a similar tendency. Mr. Forbes of Brookline, President of this Association, in a paper read in 1892 on tests made on a 16-inch force main 18 years old, obtained results giving a value to C of 93 with $V=1.15$ to 1.97 feet per second.

Mr. A. L. Adams, in a paper read September, 1898, American Society Civil Engineers, gives values of C for cast iron pipe for all except very low velocities, as follows :



Curved Pipe Over Rail Road.

	Clean Pipe.	Rough Pipe.
30-inch	C=129.00	C=97.
36- "	C=133.00	C=101.
42- "	C=136.	C=105.
48- "	C=138.	C=108.
54- "	C=140.	C=110.
60- "	C=142.	C=112.
66- "	C=144.	C=114.
72- "	C=146.	C=116.

The observed flow of the 30-inch conduit from Stony Brook to Fresh Pond, Cambridge, shows a marked diminution in the twelve years since it was laid. I regret that no exact measurement has been possible to determine the amount of this loss in flow.

From this it would seem that a somewhat larger allowance for tuberculation and roughened surfaces should be made than is often done. In the Kutter formula, n=.0135, and in large sizes and medium velocities, C=100 to 110, may be allowed. This will give results a little smaller than E. S. Gould's formula, adopted from Darcy, using the coefficients for rough pipe given in his little book on "Practical Hydraulic Formulæ."

Compared with clean cast iron pipe, steel pipe, owing to its construction and the inequalities in its inner surface, must at first be at somewhat of a disadvantage as regards discharging capacity. Owing, however, to the more rapid fouling of the cast iron pipe, this in a measure disappears in time. For determining the flow in riveted pipe, comparatively little reliable data at present exists.

Some data has been obtained by Hamilton Smith in California.

Mr. Herschel has made some careful tests in the New Jersey pipes of 42-inch and 48-inch diameter. (See "115 Experiments on the Carrying Capacity of Large Riveted Steel Conduits," 1897), which have been well adapted for use by Prof. Merriman in his "Treatise on Hydraulics" (Ed. 1897.)

From this it would appear that C=98 would apply to 48-inch pipe of steel four years in use for velocities over 2 feet per second.

Mr. Emil Kuichling has also made some careful gaugings of the flow in the Rochester, N. Y., pipe. (See "Annual Report of Executive Board," 1895, 1896, 1897.) For 38-inch pipe four years old, Mr. Kuichling obtained C=113.58 with V=1. ±C=115.38, V=3.25, and C=109.25 and 106.50 V=3.75. Mr. Kuichling's test of the old conduit, in use sixteen years, gave for the 36-inch pipe C=85.00 and for the 24-inch, C=83.00.

A test made on a 14-inch pipe of steel in New Westminster, B. C., in 1896, gave C=73 for V=1.35.

Mr. A. L. Adams, at Astoria, Ore., in testing a compound 14-inch and 16-inch line, obtained C=112.30. Mr. Adams gave in his paper in 1898, above referred to, as a suggested value of C for riveted pipe; for clean pipe C=111, rough pipe, 20 per cent. less, or C=89.00. These values seem to me about an average, and can safely be used.

Steel pipe, as commonly made, consists of an inside and an outside course, alternating; the inside diameter of the outside course being just twice the thickness of the plate larger than the inside diameter of the inner and smaller course. Some attempt to reduce the resulting loss of head has been made by making the courses tapering, with a large and small end, the small end of one plate fitting into the large end of the next plate. The small end being placed in the direction of the flow, and so a gradual reduction in diameter or taper being made. If the results obtained by Mr. Herschel are correct, this does not accomplish the object sought, for, as demonstrated by Prof. Merriman, in his "Treatise on Hydraulics," the sudden enlargement of section at the end of the plate increases the loss of head more than the reduction of the section would if the plates were reversed, or if it were made with inside and outside courses.

Mr. Herschel's friction coefficients are generally larger for pipe with taper joints than for pipe with cylinder joints.

Suppose, now, we apply the figures by way of illustration, to the Cambridge, Mass., pipe, 40-inch diameter, already referred to. Assume that the value of C for cast iron be 105.00, for steel to be 90.00, this would require the steel pipe to be 42 inches in diameter to deliver the same amount of water as a 40-inch cast iron, or to produce the same loss by friction head. The thickness of the plate used was 5-16 inch. The increased amount of metal in a 42-inch pipe, over that in the 40-inch pipe used, will be about 7.5 pounds, allowing for laps, rivets, etc. The pipe, as built, took 3,711,000 pounds of metal, and cost in the ground—including all special work, extras; etc., $116,119.77, or $3\frac{13}{100}$ cents per pound. The length was 24,133 feet, or $4.81 per foot. As valves and special fittings were all 36-inch, no increased cost would have been incurred for these, in making it 42-inch, and it seems fair to estimate it by the pound at the price actually paid, i. e.: .0313 x 7.50 =$.235 per foot increased cost, or about 5 per cent. on $4.81, so that the figures given in the first of this paper as a saving of $31\frac{1}{2}$

per cent. should strictly be $26\frac{1}{2}$ per cent. for pipe of equivalent capacity.

The proposed attempt to reduce the friction in a steel pipe by the engineers in charge of the works projected at Coolgardie, Australia, will be watched with great interest.

Owing to the great length of the line, some 328. miles, and the high price of coal in that region, the matter of friction became a very serious one. It is now proposed to have no riveting at all on the pipe, which is to be 30 inches in diameter, its entire length. The plate is to be rolled so as to make two half sections about 28 feet long; the edges of these plates are slightly upset and inserted into the slots of a "locking bar" which are then pinched together firmly, closing the two horizontal seams. The vertical or roundabout joints are to be made up with a wrought iron sleeve with lead caulked in place. By thus reducing the probable friction head, the value of C. was taken as 98.00 in the estimated delivery of this pipe. This is probably the largest work of the kind ever attempted. (See Engineering News, February 10, 17, October 13 and December 29, 1898).

PROTECTIVE COATING.

The thickness of the plates from which the steel pipe is made, is so much less than cast iron, that a more adequate protective coating than that usually given to cast iron, has been deemed necessary. Asphalt in some form may be said to be the base of most of the preparations now proposed for this purpose. There can be no doubt, I think, of its great value for this use. The different mixtures and compounds used for coating may all be classed by the two methods of applying it to the pipe.

By the first, the mixture is heated in a large upright tank, and the pipe, after being thoroughly cleaned and heated, is dipped into the tank, and after remaining long enough to become of the temperature of the mixture, it is withdrawn and allowed to cool, when the pipe is ready for shipment. A very interesting description of this process, using what is called "Mineral Rubber," analysis, test of materials, etc., with illustration, is given in the Annual Report of Mr. Cappelen, City Engineer of Minneapolis, Minn., for 1897.

By the second plan, the pipe after heating, is dipped vertically into the coating material, and then placed in an oven where it is baked until the coating forms a kind of japan or enamel, covering the pipe. The 40-inch pipe line laid in 1896, in Cambridge, was

coated by this method, using the "Sabin coating," so called—as made by E. Smith & Company of New York.

In order to determine experimentally, something of the value of this coating as a protective agent, a number of cast iron, steel and wrought iron plates were obtained and put, some in water, some in sand and some in clay soil. Those in the water were put in the draught conduit at the engine house, so that they were subject to much the same conditions as the interior of a pipe. The pieces were carefully weighed before being placed, and then after a little over a year's test, were taken out and examined, and weighed over again. The result is show in the following statement:

Trial Tests of Unprotected and Protected Metal Under Various Conditions at Cambridge, Mass.

Kind of metal.	Coating.	Situation of pipe.	Original Weight. lbs.	oz.	dr.	Weight when examined. lbs.	oz.	d.	Percentage of increase.	Remarks.
W'rt Iron	Uncoated......	Water....	4	15	1	5	1	4	1.5	Badly tuberculated and rusted; worst of lot.
"	"	"	4	6	12	4	9	0	3.1	Badly tuberculated and rusty.
"	"	Sand.....	4	15	14	5	1	8	2.0	Very rusty; sand adhered to plate.
"	"	Clay......	4	5	10	4	6	4	0.89	Rusty.
Steel....	"	Water....	4	7	11	4	8	8	1.1	Rusty and tuberculated, but not as badly as iron.
"	"	"	4	5	0	4	6	8	2.1	Rusty and tuberculated.
"	"	Sand.....	4	5	6	4	5	12	0.54	Much rust.
"	"	Clay......	4	9	3	4	9	8	0.4	Somewhat rusty.
Cast Iron.	"	Water....	20	2	8	20	6	0	1	Badly rusted and tuberculated.
" ..	"	"	19	6	8	19	9	8	0.96	Badly rusted and tuberculated.
" ..	"	Sand.. ..	19	10	13	20	0	4	1.7	Badly rusted; sand adhered to plate.
" ..	"	Clay......	19	13	10	19	13	8	....	Somewhat rusty.
Wr't Iron	Single coat...	Water....	4	14	11	......			....	In good condition; no rust.
"	"	"	4	9	6	......			....	Good condition.
"	"	Sand.....	4	9	4	......			....	Fairly good condition; some rust spots.
"	"	Clay......	4	13	11	......			....	Good condition; little rust.
Steel.....	"	Water....	5	11	11	......			....	Fairly good, some little rust.
"	"	"	5	13	2	......			....	Fairly good.
"	"	Sand.....	4	11	0	......			....	Fairly good.
"	"	Clay......	5	5	8	......			....	Fairly good.
Cast Iron.	"	Water....	19	2	15	......			....	Fairly good; little rust.
" ..	"	Sand.....	19	4	6	......			....	Good condition.
" .	"	Clay......	20	8	2	......			....	Good.
Steel....	Double coat..	Water....	5	11	13	......			....	In good condition.
"	"	"	5	6	8	......			....	Good condition.
"	"	Sand......	7	2	12	......			....	Very good condition; bright and clean.
"	"	Clay.....	5	8	10	......			....	Very good.

After this examination, the pieces were put back in the same places for examination the second year. Some of the pieces placed in the water were lost, but those found showed the same general characteristics as at the first examination, but with no increase of weight.

This experiment indicated that unprotected, the wrought iron plate was most affected by oxidation under the three conditions tried; that steel plate was affected less, and cast iron the least of any. It showed also that the protective coating was efficient in keeping all the metals tried in good condition. The superiority of the coating over that ordinarily applied to cast iron was also demonstrated by examination of the line of pipe laid in the reservoir at Payson Park. Some 800 feet of 40-inch pipe $\frac{1}{4}$ inch thick were laid on the bottom of the reservoir, and were kept constantly covered with water for two years. When the water was drawn down, the steel pipe was in good condition, and the coating bright and sound. All the cast iron pipe and fittings, coated with the ordinary coal tar dip, were badly rusted and tuberculated.

Mr. Isaac W. Smith, in a paper read in 1898, before the American Society of Civil Engineers, states that at Portland, Oregon, the first supply put in, 28 years ago, has an 18-inch main made of No. 6 plate iron, coated with asphalt. "It now appears perfectly clean and sound; a part of this pipe being still in use, under 90 pounds pressure."

The 30-inch main laid there twelve years ago was also found clean and in good condition.

DURABILITY.

The question of the durability of steel pipe is one about which some uncertainty exists, as experience with its use for long terms has not yet been extensive enough to warrant any definite conclusions. The record of wrought iron in California, with the water and soil there found, has been long and satisfactory. The same may be said of the wrought iron pipe in Rochester, N. Y.

Some question has been raised as to the relative resistance to corrosion of wrought iron and steel. My own experience and observation, already referred to, would indicate that, of the two metals, steel was the superior. Exactly what the difference in life of the two metals, cast iron and steel, may be taken to be, it is not

possible now to state; but while it may be conceded that with its greater thickness and probable less tendency to corrosion, cast iron will, in most soils and water, last longer than steel—although this has not yet been proven,—this difference does not seem likely to be great enough to affect disastrously the many advantages possessed by steel for the purposes as before defined.

The following is a list of such pipe lines as I have been able to learn of, with data as to construction:

Locality.	Date.	Material.	Coating.	Length. Miles.	Diameter.	Thickness.
Rochester, N. Y.......	1873–4	Iron Plate	Asphalt	9.62	36"	$\frac{3}{16}$"
" "	1873–4	" "		2.92	24"	$\frac{3}{16}$" to $\frac{1}{4}$"
" "	1893–4	Steel Plate	Sabin Coating	26.51	38"	$\frac{1}{4}$ to $\frac{3}{8}$"
E. Jersey Water Co.....	1892	" "	Asphalt	21.00	48"	$\frac{1}{4}$ to $\frac{3}{8}$"
" " " "	1892	" "	"	5 00	36"	$\frac{1}{4}$"
" " " "	1897	" "	"	5.00	48"	(?)
New Westminster, B. C..	1892	" "	"	13 40	14"	
Portland, Ore	1893	" "		24.00	33"	0.213"
" "	1894	" "			35" & 42"	
Astoria, Ore	1895	" "	Cal. Asphalt	3.00	16"	0.134"
" "	1895	" "	" "	1.00	14"	0.109"
Cambridge, Mass......	1895	" "	Sabin Coating	4.57	40"	$\frac{5}{16}$ & $\frac{1}{4}$
Allegheny, Pa.........	1896	" "	" "	10.00	60"	
Pittsburgh, Pa.		" "	Asphalt	1.39	50"	$\frac{5}{8}$", $\frac{6}{8}$", $\frac{7}{8}$"
New Bedford, Mass ...	1896	" "	"	8.05	48"	$\frac{5}{16}$"
Spokane, Wash.	1894	" "	"	4.00	42"	No. 7 gage
" "	1899	" "	"	4.00	24"	No. 7 gage
Syracuse, N. Y.........	1893	" "	Cal. Asphalt	1.21	54"	$\frac{5}{16}$"
Brooklyn, N. Y.	1896	" "		15.00	66"	
Duluth, Mich	1896	" "	Asphalt	3.00	42"	$\frac{1}{4}$ to $\frac{1}{2}$"
" "	1896	" "	"	0.28	60"	$\frac{3}{8}$"
Ogden, Utah...........		" "	Cal. Asphalt	0.87	72"	
Minneapolis, Minn.....	1897	" "	Mineral Rubber	6.49	50"	$\frac{5}{16}$ & $\frac{3}{8}$"
Coolgardie, Austr'a. ..	Proposed	" "	Asphalt	328.00	30"	

WATER PIPES ON METROPOLITAN WATER WORKS.

BY DEXTER BRACKETT, C. E., ENGINEER DISTRIBUTION DEPARTMENT METROPOLITAN WATER BOARD.

[*Read January 11, 1899.*]

Mr. President and fellow members: In a moment of weakness I promised the President that I would say something in regard to the pipes used in connection with the Metropolitan Water Works; but I am very much afraid that I shall not succeed in adding much of value to what most of you already know in regard to the subject, as our work so far as the use of pipes is concerned, does not present any radical changes from customary usage.

During the past few years pipes made of steel plates from $\frac{1}{4}$ to $\frac{3}{8}$ of an inch in thickness have, as you all know, been used to a considerable extent for mains of large size, instances of which will be brought to your attention this afternoon. The advisability of using this class of pipe for our work was carefully considered, as many of our mains were to be of large size. The thinness of metal in the steel pipes renders the length of life of the pipes very much dependent upon the ability of the coating to prevent corrosion of the iron, and where pipes are to be laid in public streets, as ours were to be, and the coating constantly exposed to injury on account of public work of various kinds, I do not think that it would be possible to protect the coating from damage, except at a very great cost. If the coating is not thoroughly protected from injury, there is, to my mind, a very serious doubt as to whether it is advisable to use so thin a material.

As you know, Boston and vicinity are not noted for the regularity of street lines, and the frequent angles required in the pipe lines to conform to the changes in direction, both horizontal and vertical, many of which, due to underground objects, were only discovered

when the trenches were opened, would have delayed the work and increased its cost. It would also have been impracticable to have left the pipes exposed in the streets for any considerable distance in order to apply a water pressure test, which is absolutely necessary with riveted pipes.

For this, and perhaps some minor reasons, it was decided to use cast iron as the material for our pipes. A 36″ riveted steel pipe about 40 feet in length was used in crossing over a water course.

The next question to be determined was the thickness of metal to be used in the pipes. On an order for a few hundred tons of pipes, the question of thickness and consequent weight is not of much importance, but when 75,000 tons of pipes are to be furnished, the thickness of the pipes as affecting the cost becomes a question for careful consideration. The thickness of cast iron water pipes used in different places varies very largely, and the tendency during the past ten years has, I think, been toward the use of thinner pipes, particularly for the larger sizes. When pipes were cast horizontally, and the tops of the castings were in many instances one quarter of an inch thick and the bottoms three quarters, a much larger margin of safety was necessary than at the present time when the thickness at different points seldom varies more than a few hundredths of an inch. I think that the thickness of pipes has been very largely based upon the practice of former years, when the work at the foundry was not done with the precision which now obtains.

The thickness of metal which it is necessary to use in cast iron pipes, to withstand the static pressure due to the elevation of water in a reservoir, is for the smaller sizes of pipes very much less than the thickness used. For example, assuming a factor of safety of five for the strength of the iron the thickness required for a 6-inch pipe to withstand a pressure of 100 pounds would only be about $\frac{1}{10}$ of an inch, that is with no allowance for water hammer, but simply for a static pressure of 100 pounds per square inch, the thickness of metal needed would be $\frac{1}{10}$ of an inch. But as you all know, a cast iron pipe of that thickness could not be made nor handled. In determining the proper thickness for cast iron pipes allowance must be made for the pressure due to water hammer, for inequality in manufacture, for safety in handling, and for deterioration. After a careful study of the subject it was decided to use the following formula in determining the thickness of the several sizes of pipes to be used :

$$t = \frac{(p + p')r}{3300} + 0.25$$

r = the radius of the pipe in inches.

p = the static pressure in pounds per square inch.

p′ = the allowance in pounds for water hammer.

0.25 = allowance for inequality in manufacture, deterioration, and safety in handling.

p′ = 70 for sizes from 60″ to 42″ inclusive.

p′ = 75 for 36″ pipe.

p′ = 80 for 30″ pipe.

p′ = 85 for 24″ pipe.

p′ = 90 for 20″ pipe.

p′ = 100 for 16″ pipe.

p′ = 110 for 12″ pipe.

p′ = 120 for sizes from 10″ to 3″.

THICKNESS OF CAST IRON PIPES.

Class.	A	B	C	D	E
Head, Ft.	115	150	200	250	300
Pressure, Lbs.	50	65	87	109	130
Diameter, Inches.	Thickness in Inches.				
4				.40	.45
6				.46	.50
8				52	.55
10				.60	.63
12		.57	.61	.65	.69
14		.61	.65	.70	.75
16		.65	.70	.75	.81
20		.73	.79	85	.92
24		.80	.87	.95	1.03
30		.92	1.00	1.10	1.20
36	.93	1.03	1.13	1.25	1.36
42	1.01	1.14	1.27	1.40	
48	1.15	1.25	1.40	1 55	
54	1.23	1.35	1.53		
60	1.35	1.50	1.70		

This formula gives thicknesses which are somewhat less than have been used on the Boston works, and in many places in this vicinity. The cost of the pipes used on the Metropolitan works has been more than $200,000 less than it would have been had they been made of the thicknesses used on the Boston works. Up to the present time 72,900 tons of pipes and 2,746 tons of special castings have been purchased for the work, and of this quantity more than 80 per cent have been of sizes from 36 inches to 60 inches in diameter.

The form of sockets used is the common one, being slightly less deep than those used on the Boston works and deeper than the shallow sockets used in Providence and Newton. For crossing under the Charles and Mystic rivers 36-inch pipes were used, having a special form of socket and of extra thickness, to allow for the deterioration in the salt water. These pipes are 1.65 inches in thickness, and weigh 677 pounds per linear foot, or 8,500 pounds per length. For these pipes three types of joints were used. The first differed from the ordinary pipe joint by substituting three turned grooves for the usual single groove in the bell. These grooves were for the purpose of holding the lead more securely. In the second type the bell was the same as in the first, but the spigot was smoothly turned with a straight taper to a standard pattern, so as to be interchangeable. After inserting one of these tapering spigots in the bell of a pipe, and running the joint with lead, the spigot could be withdrawn, and when again inserted would make a tight joint. The third type was a flexible ball-and-socket joint. The spigot end of the pipe was made larger and thicker than in ordinary pipes, and turned truly spherical. On the inner surface of the bell, 8 inches in from the end, there is a raised ring 1 inch in width, which is turned to fit the spherical surface of the spigot end. In the bell between this ring and the end of the pipe there are five grooves to hold the lead, of which about 280 pounds were used for each joint. This joint permitted a deflection of about one in ten, and was designed so that the whole deflection could take place without having any portion of the spigot end project into the waterway.

TESTING OF MATERIAL.

As the pipes form a very important part of the work, much care has been given to the details of their manufacture. With every

day's work at each pipe shop four test bars were made and broken to determine the transverse strength of the iron used. This test was used rather than the test of the tensile strength of the iron, as very hard and brittle iron will often show a high tensile strength, but will not withstand sudden shocks. In connection with the manufacture of our pipes more than 5,000 test bars have been made and broken, and I think I can safely say that as the result of these tests the quality of the iron used has been kept at a much higher standard than is usual. The specifications require that bars 2 inches by 1 inch in section, placed flatwise on supports 24 inches apart and loaded at the center, shall support a weight of 1900 pounds and show a deflection of 0.3 of an inch before breaking.

During the early part of the work difficulty was experienced in meeting these requirements at some of the foundries. But an improvement was made in the quality of the iron, and for the past two years there has been no difficulty in fulfilling them, and at some of the foundries the test bars show an average transverse strength of between 2,300 and 2,400 pounds with a deflection of from 0.4 to 0.45 of an inch.

SMOOTHNESS OF PIPES.

Considerable attention has been given to having the interior surface of the pipes as smooth as possible. In making the pipes the outside surface of the core which forms the inner surface of the pipes is blacked or covered with a thin coating of coal dust and molasses, which at most foundries is applied with a brush. The men doing this work are very apt to be careless in applying the coating, leaving the surface of the core covered with small ridges and grooves, which are reproduced on the interior of the pipes. At one foundry the experiment was successfully tried of applying this coating by means of what is termed at the foundry a "Strike." The clay core was revolved in front of a straight edge, and the blacking left true and smooth as if turned in a lathe. Where the coating was applied in this manner the interior of the pipe was very much smoother than where it was done in the other way; and there is no doubt but that the roughness of the interior of a pipe due to these ridges is sufficient to sensibly affect the delivering capacity of the pipes.

COATING.

Many experiments were tried in the hope of finding a coating for the pipes which would be a more perfect protection against the

formation of tubercles than the tar coating which is ordinarily used, and our contracts provided that, if required, the pipes should be coated with a different compound, which we might provide or require. The results of the experiments, which were made with different kinds of tar and asphalt, did not warrant any change in the previous practice, other than an endeavor to have the utmost care used in the application of the coating.

So far as our experiments have gone, the result has been rather negative; and we have not been able to find any coating which, considering probable durability and cost, would warrant any change in the material used for coating pipes at the foundries. The question is one worthy of further careful study.

At some of the foundries the ovens in which the pipes are heated before being immersed in the coal-tar bath were arranged in such a way that one end of the pipe would be very much hotter than the other, with the result that one end of the pipe would be so hot as to burn and destroy the coating, while the other end might not be hot enough. The tar-coating in the bath would not dry if it was applied to a cold pipe, and the distillation of the lighter products of the mixture is completed by the heat of the pipe after its removal from the bath. Consequently, if the pipe is too hot, distillation is carried too far, and if it is too cold, it is not carried far enough; and that is a reason why the coating of some pipes becomes soft when exposed to the rays of the sun, while in other cases it is exceedingly brittle.

A common practice in coating pipes is to immerse them in the bath for too short a time, in many cases not more than two minutes. All of our pipes were kept in the bath for five minutes, in order that all bubbles of air might be given an opportunity to escape, and that the temperature of the iron might be more uniform when taken from the bath. In other respects the coating has been applied at the several foundries in the usual manner.

The material used at all the foundries for coating pipes is, so far as I know, coal tar, but its composition varies greatly. In some cases, the crude tar is used as it comes from the gas works, and the lighter products of distillation are driven off, either by the heating of the material in the dipping tank, or, as before explained, by the heat of the pipe itself. In some cases, dead oil, which is a product of distillation of coal tar, is used for the purpose of thinning the

mixture or bath. In other cases, where the crude tar is used as it comes from the gas works, when the mixture becomes too thick in the bath, fresh tar is put in. Nowhere is linseed oil now used, nor has it been used, except in a very few instances, for many years. Many water pipe specifications call for the use of linseed oil, but the request is seldom if ever complied with, and I seriously doubt whether the pipe coating would be improved by its use. If the coating is not brittle, but is tough and smooth, I question whether it is not as good done by present methods as it would be if linseed oil were added.

The interior surfaces of nearly all of our pipes of sizes 36 inches in diameter and larger have been painted with paraffine or vulcanite applied cold with a brush. This was done by the men employed to unload the handle pipes at the several pipe yards, and being done in this way the cost has been very small. The object of doing this has been as an additional protection against rusting, in the hope that any minute holes in the covering might be covered, and that any injury done to the coating during transportation might be remedied. Both of these substances are coal tar paints, containing no linseed oil. The paraffine varnish is imported from Holland, and the vulcanite came from New York. Both of these varnishes appeared to have less volatile solvents than most of the coal tar paints and dried more slowly.

DISCUSSION.

Mr. Porter. Mr. Brackett's remarks about the necessity of protecting steel pipe against corrosion brought to my mind an interesting practice, which I presume many of the members have read about in the engineering papers during the last year, and that is what the French engineers have been doing in providing conduits for carrying the sewage of the city of Paris. It is being distributed on fields outside the city, and they are carrying it to those fields in conduits, some of which run under considerable pressure; and they have been using, as I have read, pipes having a steel core, a thin core, embedded in cement. Those are not quite the same as the cement-lined pipes which have been used in some of our New England cities, because they seem to have outside and inside of this core a sort of coarse net-work, made of steel rods, and the whole thing is embedded in a thick coating of cement. They seem to have

used these under pressures as high as a 130 feet or thereabouts, and of diameters ranging from about a foot up to three feet and a half; and they have conduits of somewhat similar construction, which I judge do not run under pressure, up to about ten feet in diameter.

It seemed to me it was a very interesting practice and worth while calling attention to at this time.

Mr. FitzGerald. How much did the pipe cost, Professor?

Mr. Porter. I can't say definitely about that, but I noticed that the price of the pipe laid and the trenches backfilled ranged from about 85 cents for the smaller sizes up to about $5 for the largest, 3½ feet. The least covering was between 3 and 4 feet in depth, and how much the excavation amounted to in other places I cannot say. Those were the prices per foot.

CLEANING A WATER MAIN IN ST. JOHN, N. B.

BY WILLIAM MURDOCH, C. E., ENGINEER WATER WORKS.

The city of Saint John is supplied with water from two sources about 12 miles apart, the east side of the harbor, which contains the larger part of the population, taking its water from Little River, and the west side supply coming from Spruce Lake.

The east side mains are three in number, as follows: No. 1, laid in 1851, 12 inches diameter; No. 2, laid in 1857 and No. 3, laid in 1873, each 24 inches diameter. Neither of the pipes had ever been cleaned and Nos. 1 and 2 had not been varnished. No. 3 however, was coated according to Dr. Smith's process. The length of each main is 4¼ miles.

The reservoir from which the supply is taken is formed by damming the river with an embankment 300 feet in length and 20 feet high, causing the surface to stand at an elevation of 160 feet above H. W. datum in the harbor, whilst the summit of the city is 130 feet above datum and five miles from the reservoir. It will thus be seen that with a gravitation system, the pressure on the summit is very low; indeed, in zero weather, it has been known to disappear entirely and the water actually fall away from the pipes and leave them empty.

The two older mains had become so foul through internal incrustation that when No. 3 was shut off for repairs and the city depended on the other two pipes, all the portions at a height of 80 feet or more above datum, comprising an area of about 200 acres and containing a population of about 8500 souls, were without water. On the other hand, with No. 2 shut off and supply coming by Nos. 1 and 3, every pipe was full and water delivered at a level of 130 feet. This was an ample demonstration of the foulness of the old mains as compared with that last laid.

In the summer of 1897, the Common Council passed an order directing that the mains be cleaned, and preparations were forthwith begun. There being no hatch boxes on these pipes, such

fittings were designed and cast, and when they were placed in position the work of cleaning began. Meanwhile a scraper was designed and constructed in the workshops of the department, the pistons being of birch, built in layers crossing the grain and bolted together as shown in cut (Fig. 1). The spindle connecting the

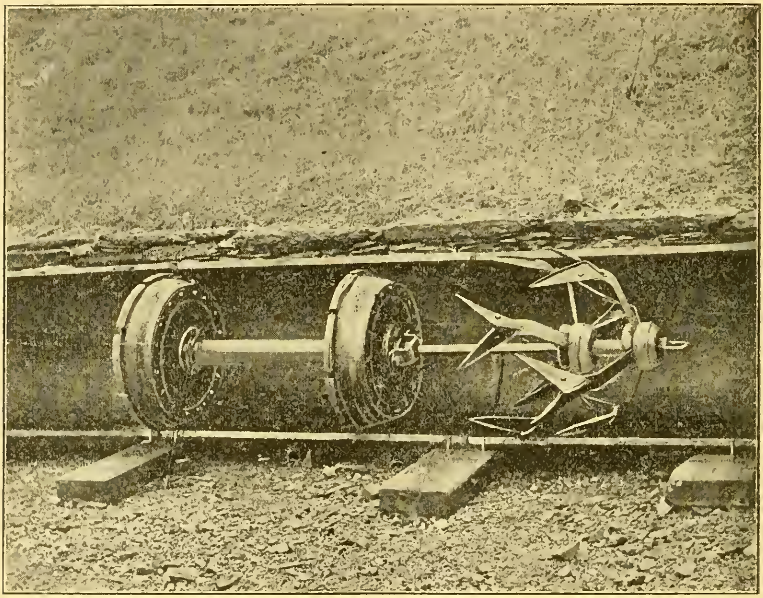


Fig. 1. First Scraper Used.

pistons is of 3 inch wrought iron pipe, and the flanges of the ordinary kinds screwed on and rivetted to prevent backing out and falling apart when inside the pipe. Projecting beyond the forward piston is an iron rod, fitted with two sets of radial arms, four in each set, sloping back, as shown in the photograph. During the operations in the year 1897 this style of arm and cutters was used, and with this we will first deal. Each arm consisted of one layer of No. 10, B. W. G. spring steel, two inches wide, and was fitted with a forged steel fish-tail scraper made of such a form that it passed over any hard obstructions and yet reduced the incrustation considerably with each cut.

The only main operated upon, thus far, has been No. 2, which

had an internal coating of tubercles varying up to about one inch in height, closely packed all over the interior surface of the pipe and resembling in appearance that of a coarse, pebbly walk. As soon as the first section, which extended from the reservoir toward the city, a distance of about 6330 feet, had been prepared with a hatch box at each end, the cleaner was sent through and given three runs in one afternoon, the time taken in each case being about 20 minutes.

There is one flushing branch near the middle of this section and another placed at Hatch Box No. 2 which had been set close to a main stop cock, (the said stop cock being shut tight). These flushing branches were left open in each case until after the apparatus had gone by. The water on such occasions was inky black, and after running about ten minutes weakened to the color of tea. In the evening when the operations were finished a two hours' run was given to clarify the water before opening the main stop cock and placing the pipe again into service.

Section No. 2 measures about 6,860 feet and reaches to the next main stop cock near the front of which Hatch Box No. 3 was placed. In order to give the first section another cleaning, the apparatus was run through both sections, a distance of about 13,200 feet. This time our cleaner came to grief, temporarily, in the folling manner: The leathers, having worn out during the first cleaning, were renewed with a harder and stiffer quality than before, but they repeatedly caught in a new joint made while inserting the hatch box. Each time the lid was removed to ascertain why the cleaner did not start, it was found firmly fixed by this imperfect butt of the two pipe ends. After twice extricating it, and again finding it caught in the same way, a jack-screw was applied to push it past this obstruction, the lid was again put on, and the water let in at 4.05 p. m, and this time it started. At each of the five flushing stations the gate was left open fully ten minutes after the cleaner had passed, and then closed. As soon as the gate was closed the cleaner again proceeded, and the scraper, *with only one piston*, reached the end of its run at 5.25 p. m., having been one hour and twenty minutes going 2.5 miles; but when 50 minutes of total stoppages are reckoned, the machine was found to have been in motion 30 minutes. As stated, only the forward part of the cleaner arrived, and search had to be made for the remainder. Nothing was done on the following day, which was Sunday, the

castaway piston, which was lying obliquely somewhere in the pipe, having but partially obstructed the flow, and the water was left on until the Monday night following.

A receiving chamber unites Nos. 2 and 3 mains, near No. 3 hatch box, and they are controlled by stop-cocks on each side of the receiver. It was therefore an easy matter to reverse the current of water in No. 3 by closing the stop-cock at the dam and opening that at the receiver, as well as the flushing branches. This was done, and men were distributed along the line to listen for a rumbling noise, which at length was heard within about a quarter of a mile of Hatch Box No. 3, from which the cleaner had been extracted. The sound was followed along the line towards the reservoir until Hatch Box No. 2 was reached, when the derelict was taken out, after having travelled nearly a mile, and crossed a valley about 90 feet in depth. It was found that the pressure of the jack-screw in forcing the cleaner past the uneven joint had cracked one of the flanges, with the result that after having travelled about 2¼ miles, the cleaner fell apart. The forward part, comprising a piston and the scraper, pushed on, but the spindle attached to the rear piston fell to the bottom of the pipe, ploughed up some dirt, and finally became embedded and jammed. The reverse current striking the piston as it did, drove it back with the spindle trailing behind. The apparatus was repaired and three more runs made through this double section of 13,200 feet, on October 29th, without any further mishap, the time taken for each run, including 10 minutes' stoppage at each of the five flushing stations, having been from 1 hour 46 minutes to 1 hour and 55 minutes. The cold weather being on when the next castings arrived, cleaning operations were suspended for the season.

On testing the efficiency of the cleaned main by shutting off No. 3 from the reservoir to the receiving chamber, where both unite, and bringing the supply through Nos. 1 and 2, it was found that the pressure in the city was as good as when No. 2 was shut and the whole supply coming through Nos. 1 and 3, thereby showing that the capacity of No. 2 had improved to such an extent that, whereas with No. 1 it had formerly delivered to a height of 80 feet only, when unassisted by No. 3, and left 200 acres of the city containing 8,500 inhabitants without water, now the whole city could be supplied without the help of No. 3, and the water rise to

a height of 130 feet above high water. The general improvement in pressure, with all the mains on, was found to be about four feet.

The operation was resumed last summer, the first run having been made June 9th, 1898, with the same apparatus as in the preceding season. After carefully studying the action of the cleaner and giving it several runs, it was found that an improvement could be made in the scraper, which was accordingly done, and each arm fitted with a steel cutter that would not clog. It was also found that the arms could be stiffened without any risk of the machine sticking, and this was done also. The final outcome of all the improvements was an apparatus of which the cut on page 338 is a photograph.

This scraper cut through all the deposit to the bare iron, an inspection at the termination of the work having shown that only the scars or imprints of the tubercles remained on the interior surface of the pipe, and it was almost as smooth as when first made.

The whole amount of material removed was not measured, as the flushing branches deliver into the brooks, and the supply of water having been abundant, the dirt was generally carried off in liquid form, the color of the liquid becoming black as the cleaner approached within one thousand feet or so of the flushing station. An estimate may be had by bearing in mind that the average thickness of the deposit was fully three-quarters of an inch, and the length of the main 22,700 feet. It will thus be seen that about 330 cubic yards were removed.

In the Marsh Creek, at the terminal flushing pipe, quite an extensive bar was formed by the material discharged from the main, the dimensions being about 12 feet by 8 feet, but the current carried a large quantity away.

When flushing into Little River, by means of three different branches within one mile of Silver Falls, the water of the Falls assumed the color of strong coffee, and Major's Brook looked like a sewer at its confluence with the Marsh Creek, though it had received the flushings of the main 7,500 feet further up. These facts are given to show the impossibility of measuring the material taken out of the pipe.

At hatch box No. 3, where the cleaner was taken out fifteen times when cleaning the upper end of the main, 108 bushels of

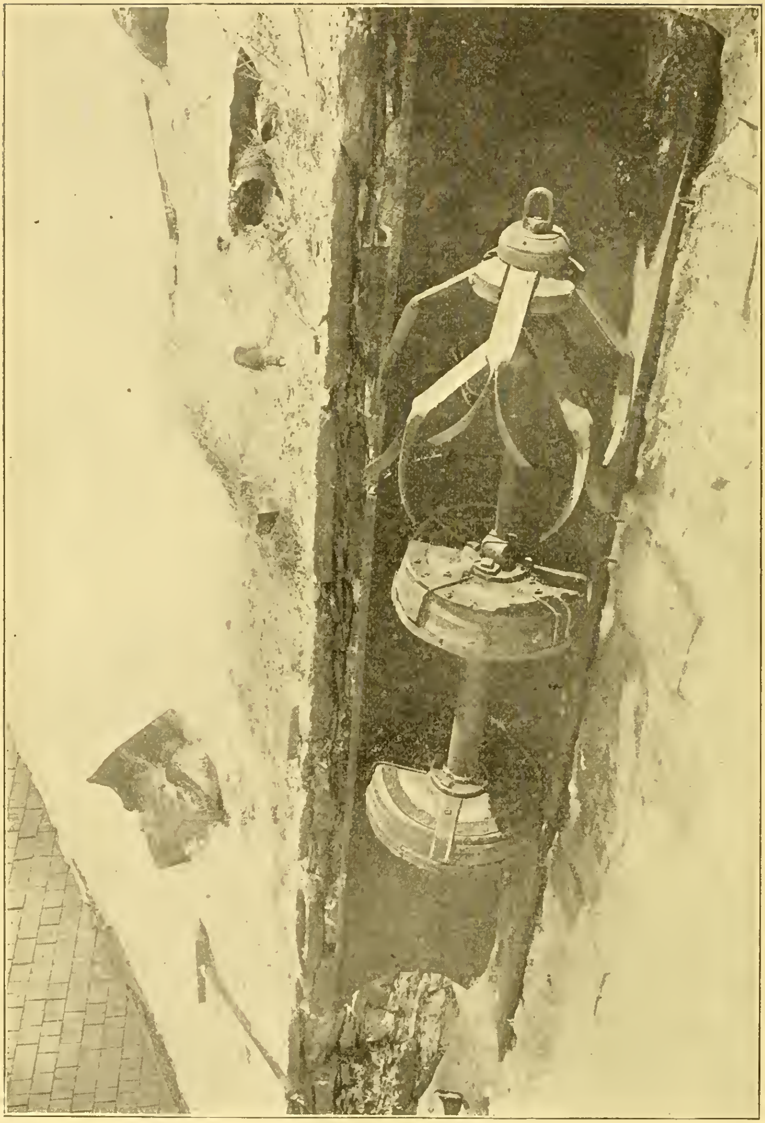


Fig. 2. Improved Scraper Used in 1898.

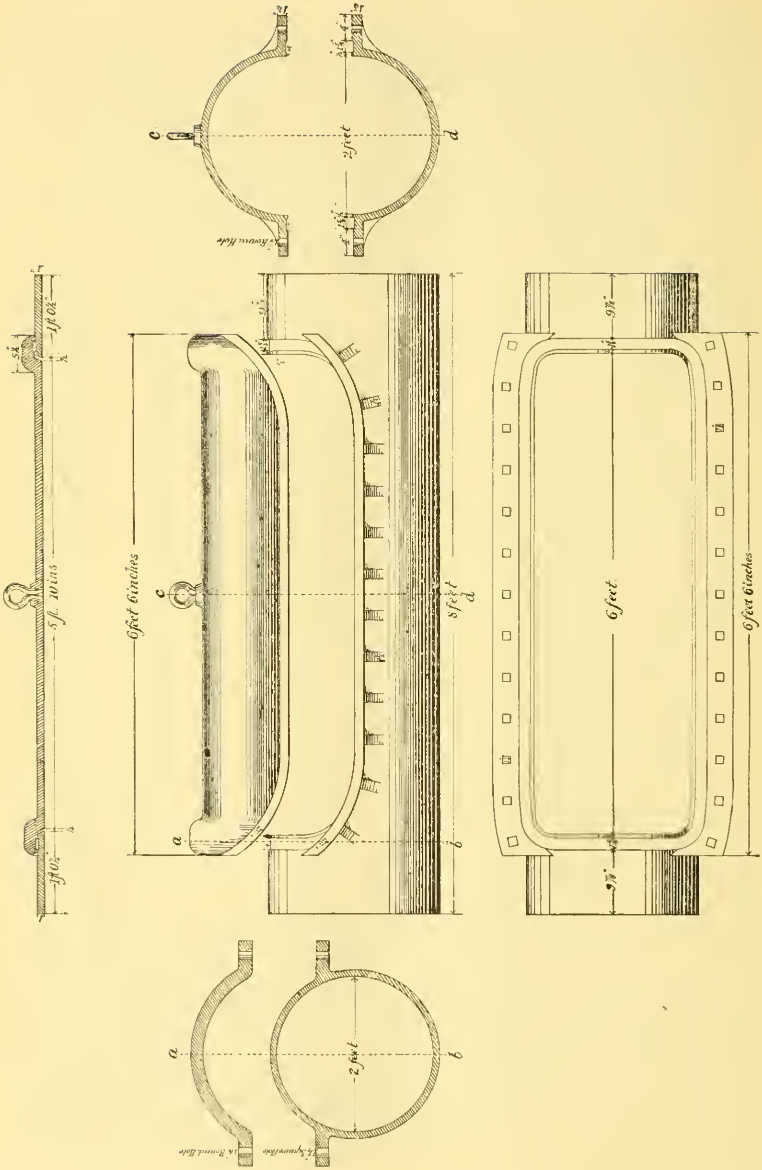
heavy material, which would not flow off by the drain, remained, and had to be taken up in buckets as it accumulated, but all the more pulverulent scrapings were carried off in the drain, and, as stated, blackened the waters of the brook upwards of a mile away. At the other hatch boxes, where the current was much stronger, an aggregate of 44 bushels had to be hoisted out.

The improvement in pressure, ascertained in the same manner as at the end of the 1897 cleaning, viz.: by sending the whole city's supply through No. 1 and No. 2, and leaving No. 3 shut off during the test, amounted to eleven feet, that is to say, that the two pipes whose combined capacity before the cleaning began was only equal to that of raising the water 80 feet, can at the present time supply the whole district and deliver up to a level of 141 feet above high water datum in the harbor.

The lightness of the cleaner is a great advantage, the entire weight being but 263 pounds, and the bulky portion being made of wood, which weighs less than the water itself, it floated along with the water. This quality was well exemplified when the broken portion was taken from the main, as already related.

The hatch boxes are of cast iron, consisting of a section of pipe with the upper half removable, and secured in place by means of screw bolts and nuts, the flanges being gasketted with Tuck's 1¼-inch round packing, which adapted itself to all the inequalities of the casting, and to the curved form of the flange. Each one weighs about 3,300 pounds, and takes 26 square-necked bolts, besides 18 feet of Tuck's packing. On completing each one, the pit was walled up with dry rubble and covered with timber, outside the city. Inside the city, the covering was arched in masonry and cement, and an iron manhole left in the crown, the manhole being large enough to pass the cleaner through.

The force employed to operate the cleaner consisted of a foreman, one mechanic, two watchers, six assistants and two express teams and drivers. The watchers walked the line on the cleaner being started, and had no difficulty in following the sound outside the city, but on coming inside the city limits, the noise of the traffic drowned the sound of the cleaner, and all that remained was to watch and wait for its arrival at the terminal hatch box. Outside the city, the grating sound as it moved along was so plain that it could be distinctly heard at a distance of 40 feet, although the


6 feet 6 inches
8 feet
6 feet
6 feet 6 inches
2 feet
5 ft. 10 ins
c
d
a
b

HATCH BOX.

pipes have from three to six feet of covering. The duty of the teams was to transport the cleaner and men back to the first hatch box for each successive run. Men were placed at flushing stations to operate the stop-cocks—two men at each. Their duties were also to assist in operating and closing the hatch boxes and placing the cleaner.

The cost of the work was as follows:

Furnishing and placing in position nine 24-inch and four 12-inch hatch boxes, being the number required on all three lines of pipe	$3,468.95
Proportionate cost of installation, chargeable to No. 2 main	$1,513.15
Cost of one 24-inch cleaner	40.00
Total cost of operating cleaner	274.42

The runs made by the cleaner through the different sections in No. 2 main numbered fifty-seven in all, and the whole distance travelled was 94.5 miles, as follows:

From Hatch Box.	To Hatch Box.	Number of Runs.	Distance in Miles Each Run.	Total Distance in Miles.
No. 1	No. 2	10	1.2	12.0
No. 1	No. 3	16	2.5	40.0
No. 4	No. 5	11	1.0	11.0
No. 2	No. 3	9	1.3	11.7
No. 3	No 5	11	1.8	19.8

It will thus be seen that the cost of cutting this main, providing and placing five hatch boxes, quarrying stone and walling therewith the pits containing them, restoring the surface of the ground and making the cleaner, amounted to $1,553.15, or $361.20 per mile, and the operating expense of cleaning the main, which measures 4.3 miles, was $6.38 per mile of pipe cleaned.

DISCUSSION.

MR. DEXTER BRACKETT.

In connection with Mr. Murdoch's very interesting and instructive paper, a brief description of similar work done on the Boston Water Works in 1886 and 1887 may be of interest.

The pipes laid in Boston from 1848 to 1868 were uncoated, and the interior surface of the pipes is covered with a coating of tub-

ercles from $\frac{3}{8}$ inch to $1\frac{1}{4}$ inch in thickness. This coating, as proved by Mr. Murdoch's statistics, very seriously affects the delivering capacity of the pipes, and, in the case of the smaller sizes, renders them practically useless for fire supply.

The pipes cleaned in Boston were not the supply mains, but the distributing pipes in the streets, the sizes cleaned being 6 inches and 12 inches in diameter. In cleaning these pipes the conditions were somewhat different from those of Mr. Murdoch, whose work was done on a pipe of larger size, where there were probably few, if any, service pipe connections. As many of the service stopcocks project into the pipes from $\frac{1}{2}$ inch to $\frac{3}{4}$ inch, it was necessary to have the scraper arranged so as to pass by such obstructions, and at the same time remove the coating of tubercles. The machine, which was very successfully used, consisted of a flexible central shaft about three and one-half feet in length, composed of coiled steel springs connecting small castings, to which were hinged two sets of steel scrapers, arranged radially around the shaft about twelve inches apart. The scrapers were kept against the sides of the pipe by coiled springs, which permitted them to turn back so as to pass taps or other obstacles. Back of the scrapers were two rubber pistons placed about two feet apart so as to ensure a pressure on the machine when passing branches. The scraper was operated in a manner very similar to that used by Mr. Murdoch, except that no hatch boxes were placed in the mains. A section was cut out of the pipe long enough to receive the scraper, which was then inserted, and the joints made with lead in the ordinary manner, except that clamp sleeves were used so that the section could be again easily removed and the scraper inserted if desired. A similar piece was cut from the pipe at the other end of the main to be cleaned, and the scraper was forced through the pipe by the ordinary water pressure, which varied from 30 to 45 pounds.

As occupants of buildings on the line of the pipes were without water while the work of cleaning was in progress, and as it was not thought advisable to pass the scraper through valves, the pipes were cleaned in lengths averaging 1,000 feet. The scraper generally passed through this distance in from three to four minutes, or about as fast as a man would walk. In a few instances the scraper was stopped by obstructions in the pipe, the one causing

the most trouble being lead which had run into the pipe at a joint. The water issuing from the open end of the pipe was the color of ink for from five to ten minutes after the scraper had passed through, and it was permitted to run until it became clear, after which the section of pipe was replaced and the valves opened. Some difficulty was experienced from the stopping of service pipes and house plumbing by rust forced into the pipes by the pressure of the water following the scraper, but this difficulty could be generally overcome by applying a force pump to the house plumbing and forcing the obstructions back into the main.

By this method the tubercles were removed from 58,000 feet of 6-inch pipe at a cost of 14 cents per foot, and from 20,300 feet of 12-inch pipe at a cost of 20.6 cents per foot. These prices include 5 cents per foot royalty paid for the right to use the scraper.

As was the case at St. John, a great improvement was made in the delivering capacity of the pipes by the removal of the coating of tubercles. Experiments were made to determine the friction in the pipes both before and after cleaning under different rates of discharge. The discharge was measured by means of a Deacon meter, and the friction head from readings of Bourdon gauges attached to the fire hydrants. Very great accuracy was not expected in these experiments, but they show very well the great loss in discharging capacity, caused by the coating of tubercles and the gain from the cleaning. It will be noticed that the discharge of the 6-inch tuberculated pipes was from 25% to 35% of the quantity which a clean-coated pipe might be expected to deliver under the same head, and that the discharging capacity of the pipe was more than doubled by the removal of the tubercles.

TUBERCULATED PIPE, 38 YEARS OLD—LENGTH, 525 FEET; ORIGINAL DIAMETER, 6 INCHES.

Observed Head. Feet per 1,000.	Velocity. Feet per Second.	Observed Discharge. Gallons.	Value of c in formula $v = c\sqrt{RI}$.	Calculated discharge of clean pipe under same h'd Darcy's formula.
1.30	0.38	33.3	29.5	120
2.50	0.57	50.0	32.2	165
6.90	0.95	83.3	32.3	275
14.40	1.13	100.0	27.1	395
19.20	1.32	116.6	27.1	455
25.40	1.51	133.3	26.8	525
33.80	1.70	150.0	26.1	600

Same Pipe, After Cleaning. Length, 525 Feet; Original Diameter, 6 Ins.

Observed head. Feet per 1,000.	Velocity. Feet per Second.	Observed Discharge. Gallons per Minute.	Value of c in formula $v = c\sqrt{RI}$.	Calculated discharge of clean pipe under same h'd Darcy's formula.
2.70	0.76	66.6	41.5	170
1.50	0.95	83.3	68.8	125
1.50	1.13	100.0	82.5	125
3.80	1.51	133.3	69.4	205
4.20	1.70	150.0	74.2	215
6.50	2.08	183.3	73.1	265
9.40	2.46	216.6	71.8	320

PROCEEDINGS.

ADJOURNED MEETING.

Parker House,
Boston, January 11, 1899.

President Forbes in the chair. The following members and guests were present :

ACTIVE MEMBERS.

E. W. Bailey, L. M. Bancroft, Frank A. Barbour, George E. Batchelder, Joseph E. Beals, James F. Bigelow, George Bowers, Dexter Brackett, E. C. Brooks, George A. P. Bucknam, George F. Chace, G. L. Chapin, H. W. Clarke R. C. P. Coggeshall, Byron I. Cook, Henry A. Cook, J. J. R. Croes, A. O. Doane, W. W. Ewell, F. L. Fales, J. N. Ferguson, L. N. Farnum, B. R. Felton, Desmond FitzGerald, F. F. Forbes, F. B. French, Frank L. Fuller, W. J. Goldthwait, X. H. Goodnough, J. A. Gould, F. W. Gow, E. H. Gowing, Richard A. Hale, E. A. W. Hammett, John C. Haskell, L. M. Hastings, V. C. Hastings, Rudolph Hering, William R. Hill, Horace G. Holden, H. R. Johnson, Willard Kent, Patrick Kieran, George A. Kimball, Cyrus M. Lunt, Frank E. Merrill, John H. Perkins, George S. Rice. George J. Ries, Harley E. Royce, A. H. Salisbury, W. J. Sando, Caleb M. Saville, John E. Smith, J. Waldo Smith, Sidney Smith, George A. Stacy, Lucian A. Taylor, Robert J. Thomas, William H. Thomas, James L. Tighe, William W. Wade, Charles K. Walker, John C. Whitney, George E. Wilde, Wm. F. Williams, George E. Winslow, E. T. Wiswell, Henry B. Wood.

ASSOCIATE MEMBERS.

Builders' Iron Foundry, Providence, R. I., by T. C. Clifford.
Chadwick Lead Works, by A. H. Brodrick.
Coffin Valve Co., by J. Alfred Welch.
Deane Steam Pump Co., by C. P. Deane
Hersey Mfg. Co., by Albert S. Glover and Samuel Harrison.
Lead Lined Iron Pipe Co., by T. W. Dwyer.
Ludlow Valve Mfg. Co., by H. F. Gould.
McNeal Pipe and Foundry Co., by I. S. Haines.
National Meter Co., by Charles H. Baldwin and J. G. Lufkin.
National Tube Works Co., by P. W. French.
Neptune Meter Co., by H. H. Kinsey.

Perrin, Seamans & Co., by H. L. Bond.
A. P. Smith Mfg. Co., by W. H. Van Winkle.
Union Water Meter Co., by F. L. Northrop.
Walworth Mfg. Co., by E. H. Rice.
R. D. Wood & Co., by Mr. Newhall.

HONORARY MEMBERS.

Engineering News, by W. M. Baker.
Fire and Water, by F. W. Shepperd.

GUESTS.

W. C. Earl and John Taylor, Weymouth, Mass.; W. T. Haines, Waterville, Me.; John Venner, Syracuse, N. Y.; W. R. Addicks, Boston, Mass.; Mr. Porter, Mr. Sweet, W. D. Kimball, William Morse, D. T. Turner, J. P. Wood and J. P. Bacon, Boston, Mass.; Mr. Ellis, Mr. Darling, Mr. Greenwood and F. P. Thorpe.

Harry F. Gibbs, Pumping Engineer, Water Works, Natick, Mass., and William T. Haines of Waterville, Maine, were elected resident active members, and John Venner, Chief Inspector of the Syracuse Water Department, Syracuse, N. Y., was elected a non-resident active member.

The President. Members who attended the convention at Portsmouth or who have read the September number of the Journal, will remember that Mr. Hill, Engineer and Superintendent of the Syracuse Water Works, at that meeting invited the Association to hold its next fall meeting in that city. The matter was left with the Executive Committee, and that committee at its meeting this morning voted unanimously in favor of accepting Mr. Hill's invitation. Mr. Hill has come on from Syracuse to be with us today, and he will now explain what we may expect if we accept his invitation. I will call upon Mr. Hill to address the Association. (Applause.)

Mr. Hill. Mr. President and gentlemen, I came here in behalf of the city of Syracuse for the purpose of renewing the invitation to this Association to visit our city. I assure you that we will feel greatly honored by your presence, and will endeavor to entertain you in a fitting manner, just how I do not care to say at present, but will try to do as well for you as we did for the members of the American Water Works Association who visited us last fall. The Yates Hotel, the best hotel in the city, I think could accommodate

all who would be likely to attend the convention. There is a large hall in the upper part of the building which would be suitable for us to hold our meetings in. The office of the hotel is situated on the ground floor, on a corner, and the entire front is of glass. The hotel people will permit us to put counters along this front for the exhibits, so each exhibitor will have not only an opportunity to exhibit his materials from the office itself, but he will in reality have a show window. For the larger exhibits the large writing room, which is just off the main hall, can be used.

The city of Syracuse is nicely situated for the holding of conventions. It is close to Niagara Falls, and if any party on leaving would like to make a pleasure trip they can go to the Thousand Islands and down the St. Lawrence River to Montreal, thence to Plattsburg, down Lake Champlain and Lake George to Saratoga and to Albany. Now we are very much in earnest in wanting you to visit us, and we would like to have as large an attendance as possible. We would like it if every member will come, and we would like to have you bring your wives and daughters and sweethearts, and we will try to take care of the ladies as well as of you. (Applause.)

The President. You have heard what Mr. Hill has said. Now Mr. Thomas of Lowell attended the meeting of the American Society there, and I think it may be interesting if he will state briefly how that Society was entertained by the people of Syracuse.

Mr. Thomas. I had the honor of attending the convention of the American Water Works Association at Buffalo, and afterwards the pleasure of visiting Syracuse with the delegates of that convention. On the way down, a journey, I think, of about 150 miles from Buffalo to Syracuse, everything that possibly could be done was done to entertain the members and their friends, the ladies included.

When we arrived there we were furnished a lunch at the Yates House, and in the evening a banquet was given us, which was indeed a grand affair. I think about 400 people were seated in the banquet hall, among them the Mayor and the Water Commissioners and many prominent citizens of Syracuse. During the afternoon the members were taken in carriages and shown the principal points of interest in the city, and the water works system, which is well worth seeing. It would be well worth a New Eng-

land water works man's time and the expense attending it to go out there and see the water works system alone. Then the Century and other clubs were opened to the members of the Association for their entertainment; and the ladies were entertained by the women's clubs. On the whole, considering we were only in the city from noon until half-past 10 or 11 o'clock at night, the citizens of Syracuse did a great deal for us, vieing with each other in making our visit as interesting and as instructing as they possibly could. I could not begin to describe to you the pleasure and satisfaction that every member of the American Water Works Association felt at the reception we received in Syracuse; and I am sure that if the New England Water Works Association goes there for its fall meeting you will all be pleased and will be spendidly entertained. (Applause.)

Mr. Bancroft. I move that we accept Mr. Hill's invitation. Adopted.

Mr. FitzGerald. I move you, Mr. President, that the thanks of the Association be extended to Mr. Hill and to the City of Syracuse for this very cordial invitation. I think an invitation that includes not only the members, but their wives and sweethearts, is one that should receive a response from every beating heart. (Applause and laughter.)

(Mr. Coggshall seconded the motion and it was adopted.)

Mr. Dexter Brackett, engineer distribution department, Metropolitan Water Board, read a paper on "Cast iron pipes used in the Metropolitan Water Works."

Mr. George S. Rice, civil engineer, Boston, gave a description of the new steel force main of the New Bedford Water Works.

Mr. E. Kuichling, chief engineer of the Rochester Water Works, sent a communication, which was read by Mr. Coggshall, concerning the old riveted wrought iron conduit in Rochester.

Mr. L. M. Hastings, city engineer of Cambridge, read a paper on "The use of steel for water mains."

Frank A. McInness, assistant engineer, Engineering Department, Boston, gave a "Description of the new salt water fire system of Boston, Mass."

The papers were illustrated by lantern slides, and the exercises were enlivened by music by the Beethoven Male Quartette.

OBITUARY.

DAVID BATCHELDER KEMPTON.—Died March 4th, 1899, aged 81 years. Joined this Association June 16th, 1886.

Mr. Kempton was actively engaged in early life in the management of vessels engaged in the whale fishery from New Bedford, Mass., and was a member of the Council of that city from 1863 to 1865, when the first steps toward the introduction of a public water supply was taken. He was one of the Commissioners who constructed the system and a member of the first Water Board, and was connected with the Water Board for over twenty-five years. In 1889 and 1890 he was a member of the Massachusetts Legislature, serving on the Committee on Water Supply. Mr. Kempton took a deep interest in the affairs of this Association, being a careful reader of its literature and a regular attendant at its Annual Conventions, where his familiar face and genial presence will be greatly missed in the future.

GEORGE E. BATCHELDER.—Died March 12, 1899, aged 63 years. Joined this Association June 19th, 1884.

Mr. Batchelder was a native of Middleton, Mass., and settled in Worcester, Mass., in 1869, representing that city in the Common Council and State Legislature. He was appointed Water Registrar in 1884 and continued in that office until his death, showing great executive ability in its management.

He was a veteran of the Civil War and a prominent Mason.

In this Association his judgment and ability was early recognized, being elected a member of the Finance Committee, 1885 to 1888, Vice-President 1892, President 1893 and Treasurer from 1894 until his death. Being one of the older members of this Association and a regular attendant at its meetings, his wise council will be greatly missed by many members who, attracted by his strong personality and kindly manner, are proud to be numbered among his friends.

JESSE GARRETT.—Died April 27, 1899, aged 65 years.

Mr. Garrett had represented the firm of R. D. Wood & Co., Associate members, at meetings of this Association since 1886, having been in the employ of this firm over 30 years, and the senior member of its staff.

He contributed a scholarly and instructive paper on "Making Cast Iron Pipe," which was published in Vol. XI of the Journal.

Mr. Garrett's courtly instinct prevented obtruding his business at meetings of the Association, while his active interest made his presence ever welcome. His loss will be mourned by a host of personal friends.

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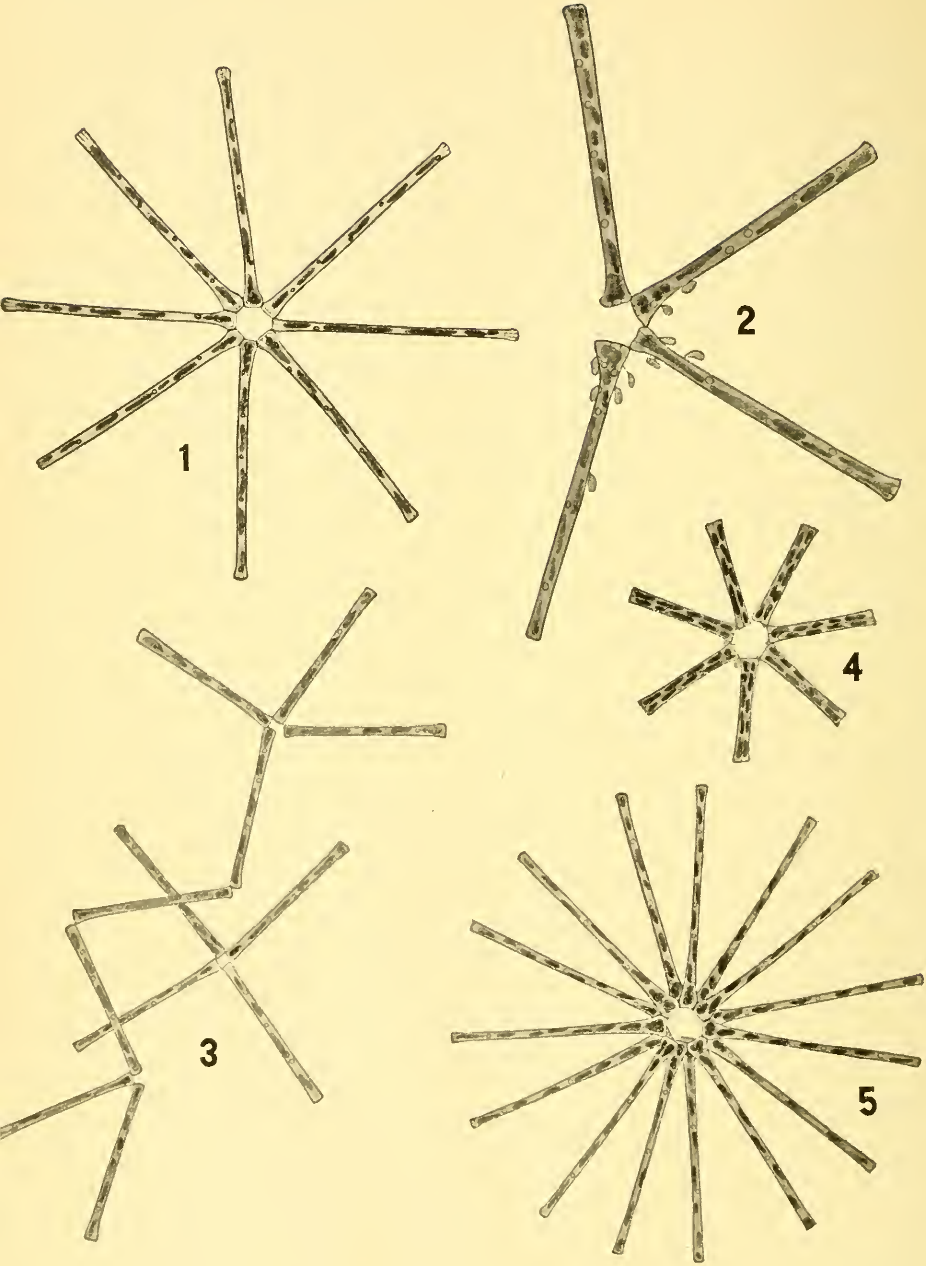


Asterionella.

Magnified 500 diameters.

NEW ENGLAND WATER WORKS ASSOCIATION.

ORGANIZED 1882.

Vol. XIV. September, 1899. No. 1.

ASTERIONELLA—ITS BIOLOGY, ITS CHEMISTRY, AND ITS EFFECT ON WATER SUPPLIES.

BY GEORGE C. WHIPPLE, BIOLOGIST AND DIRECTOR OF MT. PROSPECT LABORATORY, DEPARTMENT OF WATER SUPPLY, BROOKLYN, N. Y., AND D. D. JACKSON, CHEMIST, DEPARTMENT OF WATER SUPPLY, BROOKLYN, N. Y.

[*Read March 8, 1899.*]

Asterionella is one of the microscopic organisms that cause trouble in water supplies by producing objectionable tastes and odors. It is common in Massachusetts waters, and is well known to many members of this association. Its recent occurrence in enormous numbers in the water supply of Brooklyn, N. Y., has given it an importance that it has not heretofore possessed, and its continued periodic occurrence in that city has been the occasion of the investigations here recorded.

Asterionella belongs to the Diatomaceae, a group of unicellular plants characterized by the possession of a siliceous cell wall. Further classification places it in the tribe Pseudo-Raphidieae and the family Fragilarieae.

A diatom cell, or frustule, is constructed like a box with an overlapping cover. There is a top and a bottom, known as the upper and lower valves, and sides, known as girdles, attached to each valve, the one fitting over the other as the cover fits over the sides of the box. The living matter inside consists of a thin protoplasmic lining, with a more fluid protoplasmic material which streams through the cell and bounds what are apparently empty

cavities; chromatophore plates, which give the diatom its brownish, or brownish-green color; oil globules; a nucleus, and probably a nucleolus. The living matter communicates with the outer world through minute openings in the cell wall, and sometimes through a conspicuous cleft, called a raphe, on the line of which are found nodules. Exteriorly, the diatom is usually covered with a gelatinous excretion.

According to the present method of classification, the various genera of diatoms differ chiefly in the shape and size of the cells, in the character of the raphe, and in the markings on the valves. Generally the valve-view of a diatom, the view looking directly at the cover of the box, gives the most characteristic shape; but in the case of Asterionella the characteristic feature is best observed in the girdle-view, the view looking at the connective sides.

The cells of Asterionella are long, linear, and inflated at the ends. In the valve-view they resemble the humerus bone in the arm, (Pl. I., fig. 5*a*); in girdle-view the ends are more expanded, but less rounded, (Pl. I., fig. 1*b*). Normally the cells are united by their extremities into star-shaped clusters, that give rise to the name, *Asterionella*. This star-like arrangement is seen in the girdle-view.

There is but one well-defined species of Asterionella found in fresh water, namely, A. *formosa* (Hassall), but many so-called varieties have been described, and some of these have been advanced by their discoverers to the rank of species. In our opinion, however, the differences that separate these various forms are too slight to warrant the multiplication of specific names, and it is questionable whether, in most cases, the variations in size and shape are sufficiently constant to mark well-defined varieties.

The typical form, Asterionella *formosa*[1], was observed in England about 1850. The frustules were described as varying in length from 55 to 80 microns[2]; as being more expanded at the basal end than at the free end, and as tapering from the base towards the extremity, (Pl. I., fig. 2*c*). The valves were said to be marked with striae 0.6 microns apart.

---

1. Rev. Wm. Smith. Synopsis of the British Diatomaceae, London, 1853.
   Trans. Royal. Micro. Soc., London, 1860, p. 149.
   Dr. Henri Van Heurck. Synopsis des Diatomeés de Belgique, 1885.
2. One micron equals .001 millimeter.

A. *formosa* var. gracillima[1] (Hantsch), (A. *gracillima*[2], Heiberg), is said to differ from the typical form by showing in the girdle-view a less expanded base and a more expanded extremity, and by being somewhat thinner in the valve view, (Pl. I., fig. *b*.) The length is stated as varying from 30 to 140 microns. According to some authorities the typical form, Asterionella *formosa*, is the most common, but recent observers agree that this distinction belongs to the variety gracillima.

Among the other varieties that have been described the following may be named, but they differ so little from the above that a detailed description is not necessary:

A. *formosa* var. subtilis,[3] Grun.
A. *formosa* var. subtilissima.[3]
A. *formosa* var. Ralfsii[4], Smith.
A. *Inflata*[5] Heiberg.
A. *Bleakeleyi*, W. Smith (Marine).
A. *notata*[6] (a variety of Bleakeleyi), Grun.

We have recently examined specimens of Asterionella from more than fifty localities in this country and abroad, and have found that all of them may be properly classed as the variety gracillima, but that there are many forms intermediate between the variety gracillima and the typical *formosa*.

The valves of most of the specimens observed were long, linear, with almost parallel sides, and with rounded inflations at the ends, as shown in Plate I., figs. 2, 4 and 5. In some cases they tapered slightly toward the extremity, and frequently there was a noticeable expansion in the middle. The inflation at the base was always larger than at the extremity, the latter being sometimes inconspicuous. The basal inflation, when large, was usually asymmetrical with respect to the major axis, as shown in Pl. I., fig. 5*a*.

In the girdle-view most of the frustules presented almost parallel sides, with a slight expansion in the middle and at the ends. The basal expansion was usually, but not always, larger than the other,

1. Van Heurck, *loc. cit.*
2. P. A. Heiberg. Conspectus Criticus Diatomaceae, Copenhagen, 1862.
3. Francis Wolle, Diatomaceae of North America.
4. Rev. Wm. Smith, *loc. cit.*
5. P. A. Heiberg, *loc. cit.*
6. Van Heurck, *loc. cit.*

and was never rounded except at the corners. The expansion at the extremity was sometimes rounded as in the valve view. Occasionally the frustules tapered towards the extremity. In many cases this was found to be due to the division of the cell, as shown in Pl. I., fig. 2*c*.

The lengths of the frustules varied from 27 to 78 microns, but the most common forms were about 55 microns long. The variations in length are shown by the following table:

TABLE I.

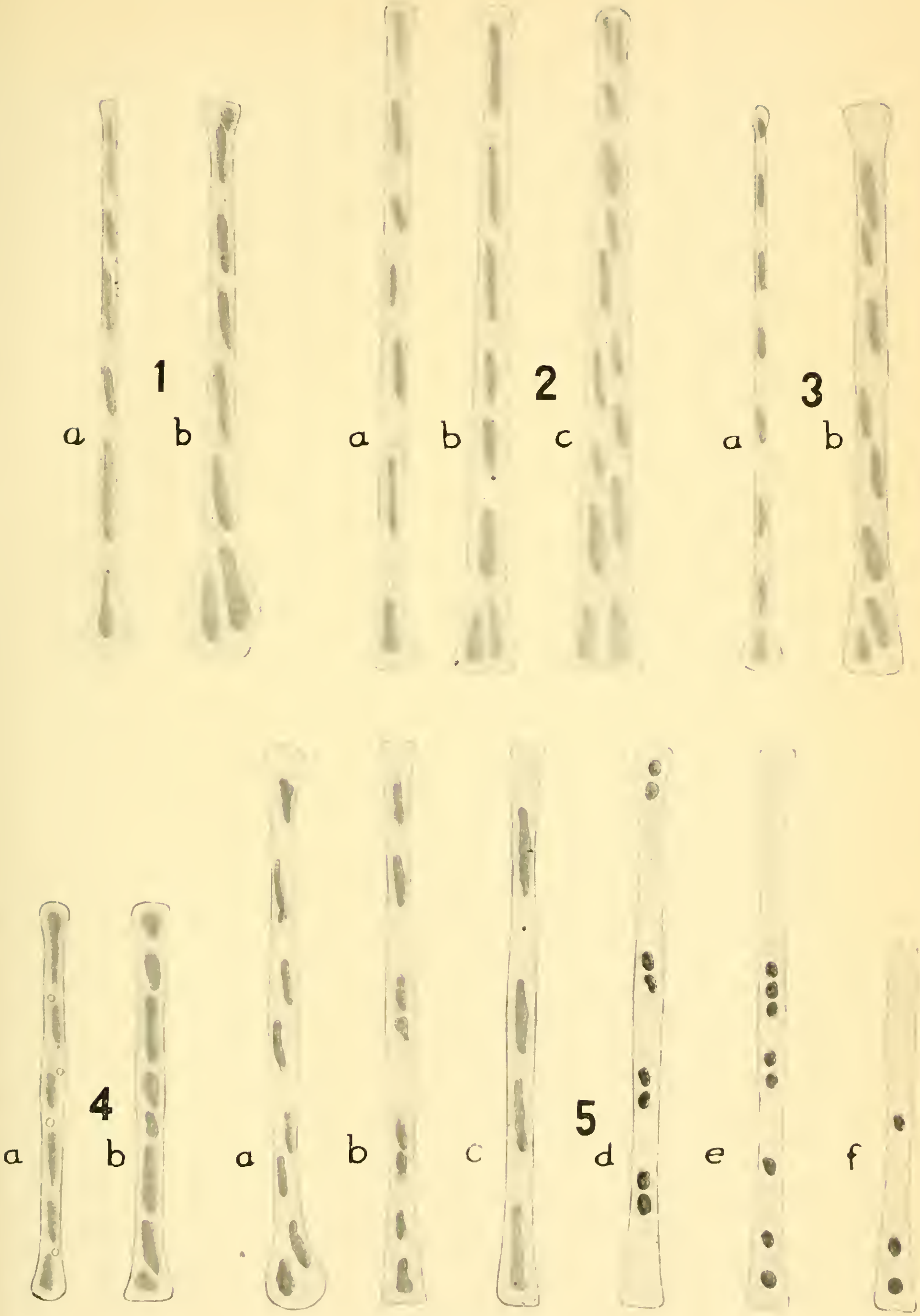
LENGTHS OF ASTERIONELLA FROM DIFFERENT LOCALITIES.

Locality.	Date.	Length in Microns.
Whitehall Pond	April, 1897	27 to 54
Ridgewood Reservoir	Nov., 1896	30
" "	Jan., 1898	40
Waltham Reservoir	Feb., 1899	36 to 45
"	Feb., 1896	53
Cape Pond, Rockport	Feb., 1899	48 to 62
Lake Cochituate	April, 1896	53
" "	May, 1891	67
Fresh Pond, Cambridge	Dec., 1895	57
" " "	Feb., 1899	63
Wenham Lake, Salem	Feb., 1899	65
Leaping Well Reservoir, South Hadley	Feb., 1899	72
Sandy Pond, Concord	Feb., 1899	78

It has been observed that the average size of Asterionella varies greatly in the same pond at different times, and that large and small cells are often present in the same sample of water.

The average width of the valves was found to vary from 2¼ to 4 microns, and was generally proportional to the length. The width of the basal expansion varied from 3¾ to 6 microns, and the width of the terminal expansion from 2½ to 4 microns. In girdle view the width varied from 3 to 3½ microns in the middle, from 4½ to 8 microns at the basal end, and from 3½ to 5 microns at the free end.

The cells were found normally in groups of eight, stellately arranged, as shown in Pl. II., fig. 1, but the number of cells in the groups varied from two to more than fifty. In many cases the cells occurred only in groups of four, as shown in Pl. II., figs. 2 and 3. The smaller forms in particular tended to form groups of four. Rarely the cells arranged themselves in a zigzag chain, as shown in Pl. II., fig. 3. The cells were held together at the corners



ASTERIONELLA.
Magnified 1000 diameters.

by a mucilaginous covering which surrounded the entire cell, but which was thicker at the basal end. It could be observed best by staining. Lumps of this mucilaginous substance are shown in Pl. II., fig. 4.

Asterionella multiplies by bi-partition. The separation of the two halves of the cell is observed first at the basal end, Pl. I., fig. 2*c*, but the division soon extends through the cell, as shown in Pl. II., fig. 4. The multiplication of the cells often gives rise to the spiral formation shown in Pl. II., fig. 5.

The method of reproduction of Asterionella is not fully understood. The only means of propagation known up to the time of this writing was that of cell division. Recently, however, we have observed that under certain conditions Asterionella forms spore-like bodies, or gonids.

In January, 1898, a mass of Asterionella was collected from Mt. Prospect Reservoir and left standing in a jar in the laboratory. It soon went through a process of decay and settled to the bottom—apparently inert. Microscopical examination showed that most of the cells had become separated from their neighbors, and were either empty or had their cell contents very much contracted. An examination made one year later showed that spore formation apparently had occurred. Minute bodies could be seen moving rapidly about inside the cells. In most of the cells they were eight in number and arranged in pairs, as shown in Pl. I., fig. 5*d*. In some the cell contents were collected in four long masses or in eight shorter ones—possibly a preliminary stage of spore formation. The spores, or gonids, were spherical or oval, from 1 to 1¾ microns in diameter, and of a greenish color. Many of them were motile, but the cilia could not be observed, though there were indications of their presence. In the fractured cells only a few spores were observed. (Pl. I., fig. 5*f*). These spore-like bodies were also seen outside the cells, but we have not yet had opportunity to trace their further development.

Asterionella is often covered with minute parasites. They are generally attached near the base of the cells where the gelatinous envelope is thickest. They apparently belong to the Choano-Flagellata, and have been described under the names of Salpingoeca[1]

1. Biolog. Centrallblatt, Bd. 12, Sept., 1892, p. 505.

and Diplosiga[2]. Vorticella are sometimes found attached to Asterionella.

The subject of the occurrence of Asterionella in lakes and ponds needs but a brief recapitulation here, as it has been already discussed at some length before this association. The organism is known to be widely scattered over Europe and North America. It is not found commonly in running brooks, in streams, or in the stagnant water of ditches and shallow pools, but rather in large ponds, lakes and reservoirs, where comparatively clear water is stored. It has been observed in salt water, but it is essentially a fresh water plant—possibly not so much because of the chemical composition of the water as because the physical conditions necessary for its growth are not usually obtained in salt water.

The published reports of the Massachusetts State Board of Health show that Asterionella has been found at one time or another in nearly all of the surface water supplies of the State, and that in many of them it appears with great regularity and in comparatively large numbers. It shows a generally uniform horizontal distribution in a pond of uniform depth, but if there is a variation in depth in different parts, it is often more abundant in the vicinity of the deep places. Irregularly shaped ponds or reservoirs that have a well-defined stream entering at one end and an efflux at the opposite end also show irregular horizontal distributions.

It has been proved experimentally[3] that the rapidity of growth of Asterionella depends upon the amount of sunlight, and from this it follows that in vertical distribution the organisms should be most abundant near the surface.

Observation has shown that this is the case, though there is a nearly uniform vertical distribution through the actively circulating water above the thermocline[4]. This is shown in Table II. During the "periods of circulation" the vertical distribution is uniform throughout.

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2. Forschungsberichte aus d. Biol. Sta. zu Plon, Teil IV, 1894.

3. G. C. Whipple. Some Experiments on the Growth of Diatoms. Tech. Quar., Vol. IX, June-Sept., 1896.

4. The thermocline is that region in the vertical above which the water is in more or less constant circulation and below which the water is quiescent.

TABLE II.

Vertical Distribution of Asterionella in Lake Cochituate, May 7, 1891.

Depth.	Number per c. c.
Surface.	3,752
10 feet.	3,736
20 feet.	3,716
..............Thermocline...............	
30 feet.	1,784
40 feet.	456
50 feet.	536
60 feet.	178

One of the most interesting facts connected with Asterionella is its periodic seasonal distribution. Normally it occurs in surface waters in the spring and autumn. Growths seldom begin during the summer or winter, though such growths are not unknown. This spring and fall distribution is illustrated by Plate III., prepared from the records of the Massachusetts State Board of Health.

It was pointed out long ago[1] that these seasonal occurrences of Asterionella were directly connected with the phenomena of stagnation. It was shown that the most regular spring and fall growths occurred in those deep ponds where the stagnation phenomena were most pronounced; and that in shallow ponds, where stagnation was more common in winter than in summer, the spring growths were more constant than the summer growths. Continued observation has testified to the general correctness of the theory that growths of diatoms occur directly after periods of stagnation, and our recent discovery of what appears to be spore formation during periods of rest lends to it additional emphasis.

Spore formation may perhaps throw light upon the sudden appearances of Asterionella in water supplies. According to Pfitzer's theory multiplication by cell division results in the increase in the number of cells by geometrical progression, and experiments have proved that this law generally holds good, and that in many cases the increase in the number of cells amounts to about 50 per cent. a week. But this law does not satisfactorily explain those sudden developments where the Asterionella increase several hundredfold

1. G. C. Whipple. Some Observations of the Growth of Diatoms. Tech. Quar., Vol. VII, Oct., 1894.

in a few days. Such an increase may be possibly accounted for by such sporadic development as we have referred to.

The number of Asterionella found in the surface waters of New England seldom exceeds 5,000 per c. c., but this number may be sufficient to produce a noticeable effect upon the quality of the water. There are some ponds, however, where much larger numbers are found. In Horn Pond, Woburn, in the reservoirs of the Winchester Water Works, and particularly in Cape Pond, Rockport, the numbers occasionally rise to 10,000 per c. c., and in the last two mentioned places to 25,000 per c. c.

But it is in ground waters stored in open reservoirs where Asterionella attains its greatest development, and where it causes the most trouble. The experiences of Brookline, Waltham and other Massachusetts cities are familiar to the members of this association, but the recent troubles in Brooklyn far surpass them in magnitude.

The water supply of Brooklyn[1] is drawn from the western portion of the southern slope of Long Island, partly from the surface and partly from the ground. The system is a complicated one. There are 15 small storage ponds and 14 driven well stations. The driven wells vary in depth. Some are shallow and draw water from the upper strata only, while others pierce the clay bed and draw water from depths of nearly 200 feet. Of the ninety million gallons consumed daily nearly one-half are drawn from the driven wells. The watershed is very sandy and gravelly, so that a considerable proportion of the water that collects in the supply ponds has percolated through the ground. Therefore the Brooklyn water supply may be regarded as essentially a ground water. The waters from the various sources are collected by a conduit system that extends for 22 miles along the southern shore of the island. The conduit terminates at the Ridgewood pumping station, where the water is pumped into Ridgewood Reservoir, the main distribution reservoir of the city. This consists of three basins that have a total capacity of about 300,000,000 gallons. Their depth is 20 feet. A by-pass has been recently constructed around the reservoir connecting the force mains from Ridgewood pumping station

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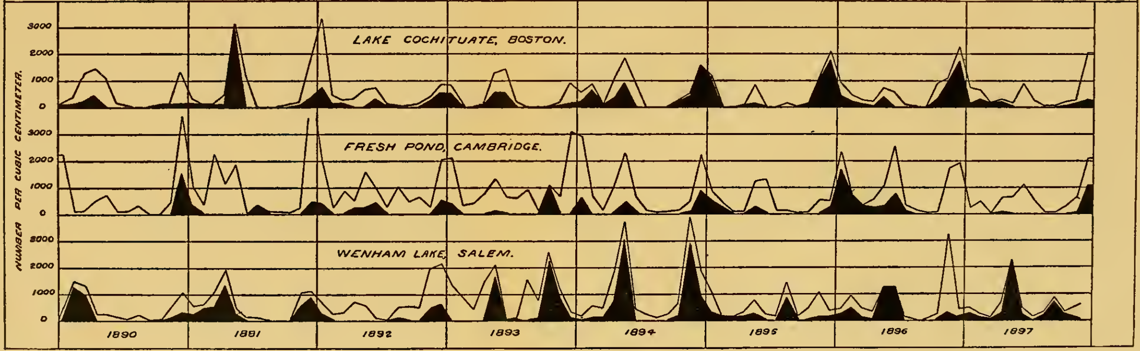
1. I. M. De Varona, History and Description of the Brooklyn Water Supply. A. S. Tuttle. The Brooklyn Water Works. Proc. Brooklyn Engineer's Club for 1898.

SEASONAL DISTRIBUTION OF ASTERIONELLA IN SURFACE WATERS.

THE PROFILE LINES REPRESENT THE TOTAL DIATOMS; THE SHADED AREAS REPRESENT ASTERIONELLA.



with the distribution system, so that any or all of the basins may be isolated and the water pumped directly into the city mains without passing through the reservoir. A high-service reservoir is located at Mt. Prospect, near Prospect Park, in the heart of the city. In these two reservoirs we have on a very large scale a typical example of a ground water—more properly a mixed surface and ground water—stored in the light.

The Brooklyn water supply was originally drawn wholly from the small storage ponds referred to, but since 1883 there has been a constantly increasing use of well water, It was not until the well water had come to form approximately 40 per cent. of the supply that the microscopic organisms began to cause trouble. During the summer of 1896 these troubles became serious, and led to an investigation on the part of the Water Supply Department conducted by Prof. A. R. Leeds, and later to a similar investigation on the part of the Board of Health, carried on at a laboratory at Rockville Centre by Dr. Hibbert Hill and Mr. J. W. Ellms. These were followed by the establishment of the present laboratory of the Water Supply Department, known from its situation as Mt. Prospect Laboratory.

The investigations made by the Water Supply Department showed that the disagreeable taste and odor of the water was caused by the presence of Asterionella in the distribution reservoirs. The water as it was pumped into Ridgewood Reservoir was almost free from microscopic life, and had no disagreeable odor, though it possessed a slight vegetable taste due to organic matter in solution. The water as it left the reservoir, however, was clouded with minute particles that formed a sediment on standing and caused a very disagreeable odor described in the newspapers by adjectives innumerable. At this time there was no by-pass around Ridgewood Reservoir, and there was nothing that the Water Supply Department could do further than to draw as little water as possible from the basin worst affected, and to hasten the construction of the by-pass.

Recent studies have made it apparent that in August, prior to the final investigations made by Dr. Leeds, the offensive odors observed in the water were caused by Anabaena rather than by Asterionella, but in November and through the winter of 1896–7 the odors were due almost exclusively to Asterionella. During the past two years growths of Asterionella have recurred at intervals

in the reservoirs, accompanied by the usual odor, but the use of the by-pass constructed in 1897 has enabled the department to supply the city with water that has contained comparatively few organisms, and that has had little or no odor. In this use of the by-pass the department has been guided by the microscopical examinations made at Mt. Prospect Laboratory.

At times the numbers of Asterionella in the water of the reservoirs have been very high. For several weeks at a time they have been above 20,000 per c. c., and occasionally they reached 50,000 per c. c. Since the construction of the by-pass the numbers in the tap-water have seldom risen above 3,000 per c. c. For more than 90 per cent. of the time they have been below 1,000 per c. c., except in the small section of the city supplied from Mt. Prospect Reservoir, where the facilities for by-passing were not as perfect as at Ridgewood.

The odor produced by Asterionella varies in quality as it varies in intensity. At first it is simply aromatic ; then it resembles the odor of a geranium plant ; and with higher numbers it becomes strongly fishy. It is caused by a substance analogous to the essential oils. The minute oil-globules may be seen in the cells, usually from two to ten in number. The intensity of the Asterionella odor in water depends upon the number of the organisms present, but varies considerably according to their condition of growth. The odor is intensified by heat, by pressure, by mechanical agitation, or by whatever agency serves to liberate the oil-globules from the cells. It is difficult to find a scale upon which to estimate the intensity of the odor ; but for convenience certain terms have been used, with the following approximate values :—A *very faint* odor is one which would not be detected by the ordinary consumer, but which could be recognized by the trained observer in the laboratory ; a *faint* odor is one which would be detected by the consumer if attention were called to it, but which would not otherwise attract notice ; a *distinct odor* is one which would be readily detected, and which might cause the water to be looked upon with disfavor ; a *decided* odor is one which would force itself upon the attention and which might make the water unpalatable. The following observations on the intensity of the Asterionella odor were recorded at Mt. Prospect Laboratory during 1898 :

TABLE III.

Table Showing the Number of Occurrences of the Asterionella Odor of Definite Intensity with Different Numbers of Asterionella.

Intensity of Asterionella Odor.	Number of Asterionella per Cubic Centimeter.								
	0 to 500	500 to 1,000	1,000 to 2,000	2,000 to 5,000	5,000 to 10,000	10,000 to 20,000	20,000 to 30,000	30,000 to 40,000	40,000 to 50,000
None or Very Faint.	46	8	5	13	0	0	0	0	0
Faint.	0	3	3	5	6	3	0	0	0
Distinct.	0	0	3	8	19	6	3	2	0
Decided.	0	0	0	0	2	8	4	1	1

This table shows that of 72 samples in which no odor or a very faint odor was observed, 64 per cent. contained Asterionella below 500[1] per c. c.; of 20 samples that had a faint odor, 55 per cent. contained Asterionella between 2,000 and 10,000 per c. c.; of 41 samples that had a distinct odor, 46 per cent. contained between 5,000 and 10,000 per c. c.; and of 16 samples that had a decided odor, 88 per cent. contained above 10,000 per c. c.

We have made several series of experiments to determine more closely the relation between the intensity of the Asterionella odor and the number of the organisms present. Table IV represents the results of one series.

A sample of water that contained 46,000 Asterionella per c. c. was diluted with varying amounts of odorless re-distilled water, and the odors of the resulting mixtures were observed both hot and cold, at the time of preparation and after standing for several hours.

1. Many of the Asterionella found in the samples of this group were only empty cells.

TABLE IV.

TABLE SHOWING VARIATIONS IN THE STRENGTH OF THE ODOR OF ASTERIONELLA FOR DIFFERENT NUMBERS OF ASTERIONELLA.

Sample Number.	Number of Asterionella per Cubic Centimeter.	Odor.					
		Fifteen Minutes after Collection.		Six Hours after Collection.		Thirty Hours after Collection.*	
		Cold.	Hot.	Cold.	Hot.	Cold	Hot.
1	46,000	Decided	Decided	Decided	Decided	Decided	Decided
2	23,000	Distinct	Distinct	Decided	Decided	Distinct	Decided
3	11,500	Faint	Faint	Distinct	Distinct	Distinct	Faint
4	5,800	Very faint	Very faint	Faint	Distinct	Very faint	Very faint
5	2,800	None	None	Very faint	Very faint	Very faint	Very faint
6	1,400	None	None	None	Very faint	None	None

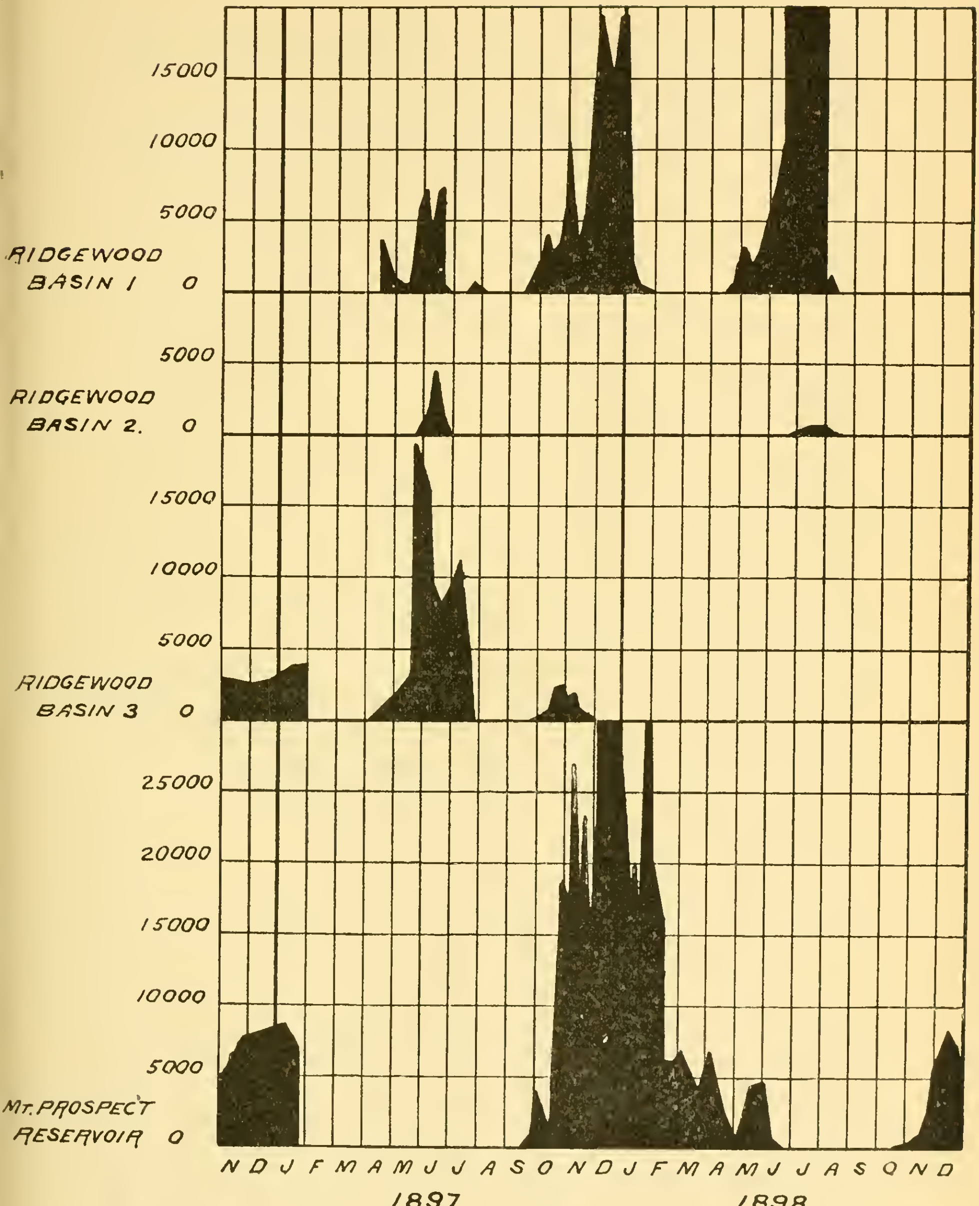
*After 30 hours the odor became modified by a moldy odor due to decomposition.

From these tables and from other similar observations, not here given, it has been found that the following relations between intensity of odor and number of Asterionella are substantially correct:

Odor.	Number of Asterionella per c. c.
None.	0 to 1,000
Very faint.	500 to 3,000
Faint.	1,000 to 5,000
Distinct.	3,000 to 15,000
Decided.	10,000 to ——

The laws that control the growth of Asterionella in open reservoirs where ground waters are stored have not been as well understood as in the case of surface waters, and for this reason the observations made in Brooklyn during the past two years are of particular interest. Briefly, these observations have shown that the same laws that govern the periodic occurrence of Asterionella in lakes and ponds hold true for small reservoirs where ground waters are stored.

The seasonal distribution of Asterionella in the three basins of Ridgewood Reservoir and in Mt. Prospect Reservoir from October, 1896, to December, 1898, is shown in Pl. IV. Between October, 1896, and February, 1897, the data were taken from the report of



NUMBER OF ASTERIONELLA PER CC.
BROOKLYN WATER WORKS.

Dr. Leeds; between April, 1897, and July, 1897[1], from the report of Hill and Ellms; and since July, 1897, from the records of Mt. Prospect Laboratory.

From this diagram it will be seen that the heaviest growths have occurred during the spring and fall in Mt. Prospect Reservoir, and in Basin 1 of Ridgewood Reservoir. In Mt. Prospect Reservoir the growth continued through the winter of 1897–8.

The records of the Massachusetts State Board of Health show that in the reservoir at Waltham, Mass., the heaviest growths have occurred chiefly in the spring and fall, but that there also, the growths sometimes continue through the winter. During the winter of 1893–4 the numbers of Asterionella were very high, ranging from 20,000 to 60,000.

The spring and fall distribution of Asterionella in the Brooklyn reservoirs led to the study of the stagnation phenomena. It was found that stagnation of the lower strata of water does occur even though the reservoirs are only about 20 feet deep. This is shown by the following table, which gives the temperatures and the amounts of dissolved oxygen at various depths in Mt. Prospect Reservoir on July 7, 1898:

TABLE V.

Table Showing the Temperature and the Amount of Dissolved Oxygen at Various Depths in Mt. Prospect Reservoir, Brooklyn, N. Y.

Depth in Feet.	Temperatures, (Fahrenheit).	Dissolved Oxygen. Per Cent of Saturation.
Surface	76.8	100
1	76.8	
2	76.8	
3	76.3	
4	76.0	
5	76.0	100
6	75.5	
7	75.4	
8	75.4	
9	75.4	
10	75.4	100
11	75.4	
12	75.2	
13	70.3	
14	69.4	
15	68.1	67
16	66.8	
17	65.3	
18	63.9	
19	62.7	24
19½	61.9	

1. No observations were made at Mt. Prospect Laboratory during this period.

It was found, moreover, that there was a considerable deposit of organic matter at the bottom of the reservoirs, and that during the periods of stagnation, decomposition of this material takes place. A sample of the deposit at the bottom of Mt. Prospect Reservoir had the following percentage composition:

Organic matter	25.87 %
Inorganic matter	74.13 %
	100.00 %

The mineral matter contained the following substances:

Silica, $Si\,O_2$	59.92 %
Oxides of iron and aluminum, $Fe_2\,O_3$ and $Al_2\,O_3$	37.53 %
Manganese oxide, $Mn\,O_2$	.50 %
Lime, $Ca\,O$	1.15 %
Magnesia, $Mg\,O$	.90 %
	100.00 %

It was found that the deposit at the bottom contained large numbers of Asterionella cells, and that these cells contained the bodies supposed to be spores. From this it is easy to conceive how, after the periods of stagnation, these spores, may become scattered through the water by the vertical May currents, and how the water, thus seeded and being well laden with food material obtained partly from the ground water entering the reservoir and partly from decomposing material from the bottom, and exposed to the stimulating action of the sunlight, may become suddenly filled with star-shaped diatoms.

With this knowledge of the biological and physical conditions controlling the growth of Asterionella in the reservoirs, it seemed desirable to learn further of its food supply. This involved an extended chemical investigation.

The food supply required by the higher plants has been carefully studied by agricultural chemists; the plants have been analyzed to find what elements were necessary for their growth, and soils have been analyzed to see if these elements were present in sufficient quantity and in a state capable of being assimilated by the plants; studies have been made also upon the relation of soils to the rotation of crops. Practically no investigations of this character have been undertaken for the microscopic organisms in

water, yet there is unquestionably as direct a relation between their required food supply and the mineral and organic constituents of water as there is between the required food supply of the higher plants and the mineral and organic constituents of the soil. If it is found by analysis that a microscopic organism contains a certain element in a certain amount, it is self-evident that the organism cannot grow in a water that does not furnish this element in sufficient quantity. This is true, however small the required amount of food material may be, and in the case of the microscopic organisms the actual amount of food required is indeed very small. With a better knowledge of the elemental constituents of the microscopic organisms and of the food material present in different classes of water, we shall be in a position to better explain why certain waters support growths of particular organism, and also to understand the reason for the "rotation of crops" among the lower forms of life. As a contribution to this knowledge we have begun with a chemical analysis of Asterionella.

In order to obtain its true analysis it was necessary to collect a large quantity of these diatoms, and at the same time to make sure that no other organisms or unorganized matter were present. The conditions for such a collection are seldom favorable, but in January, 1898, the water of Mt. Prospect Reservoir contained practically a pure culture of Asterionella, free from other organisms and from amorphous matter.

The apparatus used for collecting the Asterionella consisted of an eight-litre bottle, through the stopper of which passed a bent glass tube and the neck of a glass funnel. The funnel was covered at the top with silk bolting cloth No. 20, reinforced with a piece of strong white muslin. The water was led over the bank of the reservoir through a siphon-tube and allowed to pass through the apparatus as indicated by the arrows shown in the figure. With this arrangement, whatever heavy material was present settled to the bottom of the bottle, while the Asterionella, held back by the cloth, collected in the funnel itself. After a flow of 24 hours the Asterionella were removed from the cloth and funnel in a highly concentrated state and dried at 100° C. This process was repeated for several days until a sufficient amount of the substance was obtained. It will be seen that this apparatus may be used for collecting pure cultures of other microscopic organisms. Tap water is not always

available and it seldom contains the organisms in pure cultures and in as good condition as in the reservoir. The Asterionella thus collected in mass had a dark brownish-green color which changed to a light green on heating. It was of a gelatinous consistency and possessed so strong an odor that it permeated the whole room in which it was kept.

The chemical analysis was carried on as follows: The carbon, hydrogen and oxygen were determined by organic combustion ; the nitrogen by the Kjeldahl process. The total sulphur was determined by treating with strong, chemically pure caustic potash, evaporating, neutralizing with hydrochloric acid, and precipitating with barium chloride after the separation of the silica. The total phosphorus was determined from an aliquot part of the same solution. The mineral analysis was made according to the usual scheme when phosphates are present. It was found that the organic phosphorus remained behind in the ash, so that it is contained in the figure given for inorganic phosphorus. The results of the analysis given in the following table represent the averages of many determinations.

TABLE VI.

PERCENTAGE COMPOSITION OF ASTERIONELLA.

Carbon	18.78%	
Hydrogen	4.20%	
Nitrogen	2.20%	
Sulphur	0.61%	
Oxygen	16.69%	
Total Organic Matter		42 48%
Silica, ($Si\ O_2$)	49.48%	
Iron Oxide, ($Fe_2\ O_3$)	2.32%	
Lime, ($Ca\ O$)	1.45%	
Magnesia, ($Mg\ O$)	1.26%	
Potash, ($K_2\ O$)	1.22%	
Manganese oxide, ($Mn_2\ O_3$)	0.84%	
Phosphate, ($P_2\ O_5$)	0.67%	
Sulphate, ($S\ O_3$)	0.38%	
Total Inorganic Matter		57.52%
		100.00%

The ultimate organic analysis, as shown by the above figures, offers but little scope for discussion, inasmuch as there are no similar analyses of other microscopic organisms with which it may be compared.

In the case of the nitrogen, however, we have a few determinations with which comparisons may be made, as is shown in the following very incomplete list:

Diatomaceae—	
Asterionella	2.2* % Nitrogen
Chlorophyceae—	
Spirogyra	4.5 " "
Cyanophyceae—	
Anabaena	9.6 " "
Clathrocystis	8.3 " "

*If the silica of the organism is disregarded, this percentage becomes 4.3.

These decided differences in the percentage of nitrogen in the various classes of organisms suggest differences in the amount and kind of food material required, but we have as yet too few comparative data to draw any definite conclusions.

The most important feature of the analysis is the high percentage of mineral matter, which amounts to 57.52 per cent. of the dry weight of the organism; 49.48 per cent. of the dry weight is silica that occurs in an absolutely pure state as the cell wall. This high percentage of mineral matter renders the cells of diatoms heavier than those of most plants. From a number of observations upon the weight and number of Asterionella present in a certain quantity of water, we have calculated that the average weight of one Asterionella cell is .00000000036 gram.

From this weight we have calculated the amounts of the various mineral constituents that a water must contain in order to support a growth of 10,000 Asterionella per cubic centimeter. This number was selected because it is sufficient to give a distinct odor to water. The results, expressed in parts per million are given in the following table, together with the analyses of certain surface and ground waters:

TABLE VII.

TABLE SHOWING THE RELATION BETWEEN THE CONSTITUENTS OF ASTERIONELLA AND THOSE OF CERTAIN GROUND AND SURFACE WATERS.

Expressed in parts per million.

CONSTITUENTS.	ASTERIONELLA 10,000 per Cubic Centimeter.	SURFACE WATER. Average Composition of Boston Water.	MIXED SURFACE AND GROUND WATER, Brooklyn Water.	SHALLOW GROUND WATER, Spring Creek, New Wells Brooklyn W. W.	DEEP GROUND WATER, Roxbury Wells. Average of 21 Samples.	SHALLOW GROUND WATER, Cambridge, Charlestown and Boston Wells. Average of 31 Samples.
Albuminoid Ammonia	——	.188	.135	.035	.022	.017
Free Ammonia........	——	025	.040	.010	.011	.379
Nitrates...............	——	.250	.174	5 08	5.95	‡.041
Total Organic Nitrogen	.079	†.376	.270	.070	.044	.034
Silica...............	1.780	3.04	7.59	15.16	15.31	18.14
Ferric Oxide..........	.083	*.75	* .18	*.34	.27	1.61
Lime.................	.052	6.45	13.99	47.70	61.3	78.3
Magnesia...........	.045	1.60	8.46	24.32	26.8	82.3
Potash...............	.043	.92	——	1.84	——	——
Soda...............	.000	5.00	——	13.90	——	——
Manganic Oxide......	.030	——	——	——	§	‖
Sulphates.............	.014	4.58	7.43	1.84	36.5	65.6
Total Solids	3.600	48.5	93.6	212.0	435.0	1578.0

‡Of the 31 samples averaged, 18 contained no nitrates.

†Estimated as double the albuminoid ammonia.

*Includes oxide of aluminum.

§Of the 21 samples averaged, 10 contained no manganese.

‖Of the 7 samples analyzed, 3 contained no manganese.

It will be seen from this table that if a water holds 10,000 Asterionella per c. c., it must contain 1.78 parts per million of silica, and it follows that in order that the Asterionella may develop to that extent, the water must contain at least that amount in solution and in a condition capable of assimilation. It is more than probable that only a portion of the silica present in most waters is in such a condition that it can be utilized by the diatoms. As a rule ground waters contain higher percentages of silica than surface waters and hence they are capable of supporting larger growths of diatoms. In the table, for example, it will be seen that the Boston water, a surface water, contains 3.04 parts of silica per million, while the Brooklyn water, a mixed surface and ground water, contains 7.59 parts. These amounts of silica alone would limit the growth of Asterionella to 17,000 per c. c. in the case of the Boston water and 41,000 per c. c. in the case of the Brooklyn. In the Brooklyn water the amount of silica is often greater than this. Its amount depends chiefly upon the proportion of ground water used. The water from the Spring Creek shallow wells contains about 15 parts of silica per million, and that from other wells, 23 parts per million.

But any of the other mineral constituents may limit the growth of Asterionella in the same way. For example, Asterionella apparently requires a definite amount of manganese, an element that is often lacking in water. The records of the Massachusetts State Board of Health show that out of 40 ground waters in which manganese determinations were made, 19 contained no manganese at the time of analysis. Observations prove that this element is a variable quantity in water. It is known to be present in both the Boston and Brooklyn waters, but in the case of the analysis quoted the determinations were not made.

As a rule most waters contain lime, magesia, potash and sulphates in sufficient quantity to support heavy growths of diatoms, but iron, manganese and silica are sometimes lacking in the required quantity.

Nitrogen is an important constituent of the food supply of Asterionella, although its percentage is not large. It is supposed that in order to be utilized it must be in the form of nitrate, though it is possible that free ammonia may be made available as food under certain biological conditions. It is probable that

growths of diatoms are often limited by the amount of nitrates present. Thus it is evident from Table VII that 10,000 Asterionella per c. c. could not grow in the water represented in the last column, unless some of the free ammonia present were changed to nitrate through bacterial action.

This knowledge of the nature of the food required by Asterionella throws new light upon its periodic seasonal occurrence. During the stagnation periods the diatoms that lie in large numbers in the decomposing matter at the bottom of the reservoir. After stagnation ceases, the vertical currents carry them to the surface and hold them within the influence of the sunlight, where, under its stimulus, they develop. Meanwhile the water has increased its capacity to nourish them. During the stagnation periods the water at the bottom has been absorbing the necessary mineral and organic constituents, and at the overturning they are brought up, modified by bacterial action, and put in a condition such that they can be utilized as plant food. This action may occur in reservoirs where ground water is stored as well as in lakes and ponds.

From these facts it follows that we have a partial remedy for the occurrence of Asterionella in ground water exposed to the light. Modern engineering practice has taken strong ground that well waters should be stored in the dark, and this position is emphatically the right one. But it is not always possible to cover existing reservoirs. It seems probable, however, that if these reservoirs are frequently cleaned, the troubles from Asterionella may be very much alleviated. If the organic matter is not permitted to collect and decompose on the bottom of the reservoir, and if the organisms are not permitted to sporulate there, there is good reason to believe that such *heavy* growths of Asterionella as have been recently observed in Brooklyn[1] will not occur.

Summary. In this paper we have endeavored to establish the following facts:

1. That the common form of Asterionella is that known as *A. formosa* var. gracillima, but that great variations exist in size, shape and arrangement of the cells.

2. That Asterionella is widely distributed in nature, and that it

1. Basin 2 of Ridgewood Reservoir has been recently emptied and cleaned, and it is intended that the other basins shall be cleaned in the near future.

is found chiefly in lakes, ponds and reservoirs, where comparatively clear water is stored.

3. That its growth in surface waters occurs chiefly in the spring and fall, and is intimately connected with the phenomena of stagnation.

4. That it develops most vigorously in open reservoirs, where ground water is stored. and that its growth in these reservoirs follows the same laws as in surface waters.

5. That its odor varies in character from geranium to fishy, and that under favorable conditions 3,000 Asterionella per c. c. may impart to water an odor that will be easily recognized by the consumers.

6. That it forms what appears to be spores during periods of rest, and that this sporulation takes place at the bottom of reservoirs during periods of stagnation.

7. That its sudden developments after such stagnation periods may be due to the germination of these spores.

8. That its food supply is a definite quantity, and that the organism will not grow in a water where any one of its constituents cannot be obtained in sufficient quantity and in a form capable of assimilation.

9. That the food elements most likely to be deficient in water are silica, manganese, iron and nitrates.

10. That if reservoirs are not kept clean, stagnation tends to increase the amount of food material in the water, and that the increased amount of food material after the stagnation periods helps to explain its periodic seasonal occurrence.

11. That it is desirable that ground water should be always stored in the dark, but that it is possible to alleviate the troubles due to the growth of Asterionella in open reservoirs by keeping such reservoirs free from deposits at the bottom, thus preventing them from becoming heavily seeded with spores, and also preventing a material increase in food supply.

12. That where the use of open reservoirs for the storage of ground water cannot be avoided, they should be so designed that they may be cleaned whenever necessary, and that they may be temporarily isolated from the system whenever growths of organisms make the water unsuited for use.

In conclusion, we wish to acknowledge our indebtedness to Prof.

Charles Wright Dodge, of Rochester, N. Y., Prof. C. Schröter, of Zurick, Switzerland, and Miss Lilly Miller, assistant biologist of the Massachusetts State Board of Health, for furnishing us specimens of Asterionella from many localities; and also to express our thanks to Mr. Robert Van Buren. C. E., chief engineer of the Department of Water Supply, Brooklyn, N. Y., for permission to quote from unpublished reports.

DISCUSSION.

Prof. Sedgwick. Mr. President, I have enjoyed, as I have no doubt others have, this paper. It seems to me that it outlines practical work, which is to find out what the organisms are, what they need to live upon, and then to starve them out. That is what the paper proposes to do.

With regard to the very important statement as to the discovery of spores, I think these gentlemen, the authors of the paper, must not be disappointed if people are a little slow to accept their results, because they are so revolutionary. I think no one has ever claimed the existence of spores in diatoms—at least this sort of spores—and until they can see some of the spores developed into corresponding diatoms, they must anticipate a certain amount of skepticism on the part of botanists and biologists. And I say this without intending any criticism of the work. I have no doubt they really believe it to be true, and I have no doubt it appears to be true, and I wish I could say I have no doubt it is true. But it is so new that I think I shall have to go slow before positively accepting it. These would be virtually zoospores, and there is no intrinsic reason why they should not exist or why they could not exist. I think, however, that the argument of the authors for their existence, that such existence would explain the rapid growth of diatoms, requires a little reflection. It seems to me if you took one of these things, only a twenty-five thousandth of an inch long, which is the size given, and set it to work to build up its own substance several times over, and then to prepare the silicious case in which that substance must grow, it is going to take quite as long, if not a little longer, than to divide up a lot of ready-made diatoms lengthwise in the ordinary way in which we suppose that they grow. I may be wrong, but it seems to me that the argument may be subject to criticism, judging by the ordinary rate of growth of micro-organisms.

However, it is a very interesting theory, and it is in the right line. These were resting diatoms ; there was every reason to suppose that the protoplasm should take on some such state as they have described, and I am prepared to accept it, provisionally ; but I think that botanists generally will go a little slow until these gentlemen, the authors, see one of these zoospores actually settle down and build a case for itself and become an Asterionella. I say this simply because I have been caught in that trap myself. On one occasion I saw a mould, a Penicillium, as I thought, producing yeast. I went ahead and announced the fact, and was afterward corrected by a very eminent botanist, and very properly so, because I hadn't watched the whole chain of events clear through, and he objected on that ground. However this is a minor point. The gentlemen are entitled to praise, it seems to me, for their careful investigation. Whether they have hit it right in every instance doesn't matter. It is keeping constantly at work, which they are doing, and attempting new methods of study, which will give us eventually good results, some of which they have already obtained. For their chemical analysis alone it would have been worth while getting them on here from a point very much more remote than New York. It is no small triumph to be able to know the chemical composition of a diatom, or to be able to estimate its weight, as these gentlemen have done.

The paper is carefully prepared, it is original, and it seems to me it is entitled to high praise, and in what I have said I do not intend any hypercriticism. It is only a word of caution, because I know how skeptical the ordinary botanist will be of such a fundamental and revolutionary discovery of spores as the one here announced. I think our proper attitude is to wait, as in all other discoveries, for confirmation. This association may well congratulate itself on being able to see the silica derived from a given number of diatoms and to have percentages stated, so that it is possible to prevent their growth by keeping the silica, manganese and the like out of a water supply. The table which shows how many diatoms it takes to make an odor is a very valuable and practical one, because if we find 500 diatoms in a cubic centimetre we need feel no alarm, but if they are mounting to 1000 or more then it is time to beware. Here is a practical point of the utmost conse-

quence, it seems to me ; and there are are many other theoretical and scientific points in the paper also of great consequence.

THE AUTHORS. In reply to Prof. Sedgwick the authors wish to disclaim any originality for the discovery of spore-formation in the Diatomaceae, but simply to record the fact that these spore-like bodies are to be found in the genus Asterionella, just as they have been already found in a few other genera. Regarding the development of diatoms through the agency of spores, diatomologists are now divided into two hostile camps and the question at the present time is an open one. Our observations, so far as they have extended, seem to favor the spore theory. Some recent articles on this subject are the following:—

De la reproduction des diatomees. J. Newton Coombe. Annales de Micrographie. Jan. 1898. p. 10.

Les spores des diatomees. Castracane. Annales de Micrographie. Jan. 1898. p. 30.

Des spores des diatomees. P. Mieuel. Le Diatomiste. Vol. II, No. 26.

The Reproduction of Diatoms. J. Newton Coombe. Journal of the Royal Microscopical Society, Feb. 1899.

CHLAMYDOMONAS IN SPOT POND.

BY FREDERICK S. HOLLIS, BIOLOGIST, AND HORATIO N. PARKER, ASST. BIOLOGIST, METROPOLITAN WATER WORKS.

[*Read March 8, 1899.*]

The occurrence of Chlamydomonas is of special interest, as it is the first time during our investigations that we have found it in large numbers, and our examinations have shown that it imparts an unpleasant taste and odor to the water. It is, we believe, the first record of trouble caused to a water supply by its presence. As is the case with all such growths, the cause must be sought in the nature of the water in which the growth occurs. Spot Pond is a natural pond situated in the Middlesex Fells, in Stoneham, Mass. The original elevation of the surface was one hundred and forty-two feet, the present elevation one hundred and fifty-two feet, and the present capacity seven hundred and sixty-four million gallons. The water is thirty or more feet deep in the southern part of the pond, while much of the northern and northwestern part is little more than shallow flowage. The nature of the water which it receives is influenced by swamps situated to the north of the pond, and also by thick deposits of loam and mud at the bottom of the pond, which in some parts of the shallow flowage has a depth of twenty-five feet. This mud is to be removed and the pond otherwise improved for use as a storage reservoir of the Metropolitan Water Works. For a water which must be derived to a considerable extent from springs, the color is dark; the average color of the water of the surface for 1898 being 0.46. The water at the bottom of the pond was stagnant from the last of June until the overturn of the water during the second week of November, reaching a maximum color of 2.00 soon after the middle of September. The water was again stagnant within two weeks after the autumn overturn, and reached a color of about 1.50 during the last of January and first of February.

Microscopical examinations of samples of water from the surface, mid-depth and bottom of this pond have been made regularly since the first of March, 1898, which showed the presence at all times of a considerable growth of microscopic organisms. Diatomaceae reached a maximum spring growth in May of 1339 standard units per c. c., as an average for the surface, mid-depth and bottom. Chlorophyceae were present in small numbers throughout the period. Cyanophyceae were present throughout the period and of importance from the last of May until late in September, with a maximum growth in August. Infusoria were present in considerable variety and numbers throughout the period. The most important growth occurred in the spring, and was composed mainly of Peridinium and allied forms. The growth of Chlamydomonas appeared about the middle of August, at a time when the water had an unpleasant taste and odor, due to the decomposition of a growth of Anabaena. As this taste and odor resulting from the decomposition of the Anabaena decreased, a distinct taste and odor was observed which varied as the number of Chlamydomonas increased. The taste and odor were intensified by heating the water, and varied with the freshness of the sample and the relative number present. Small numbers of Chlamydomonas gave to the water a not unpleasant aromatic taste and odor.

Moderate numbers gave a somewhat unpleasant sweetish and oily taste and odor, and the oily and unpleasant character became more prominent as the number of organisms increased, becoming fishy and even offensive when high numbers were present. The offensive taste and odor were most noticeable in the case of water which had passed through the distribution system, and was due to the disintegration of the Chlamydomonas.

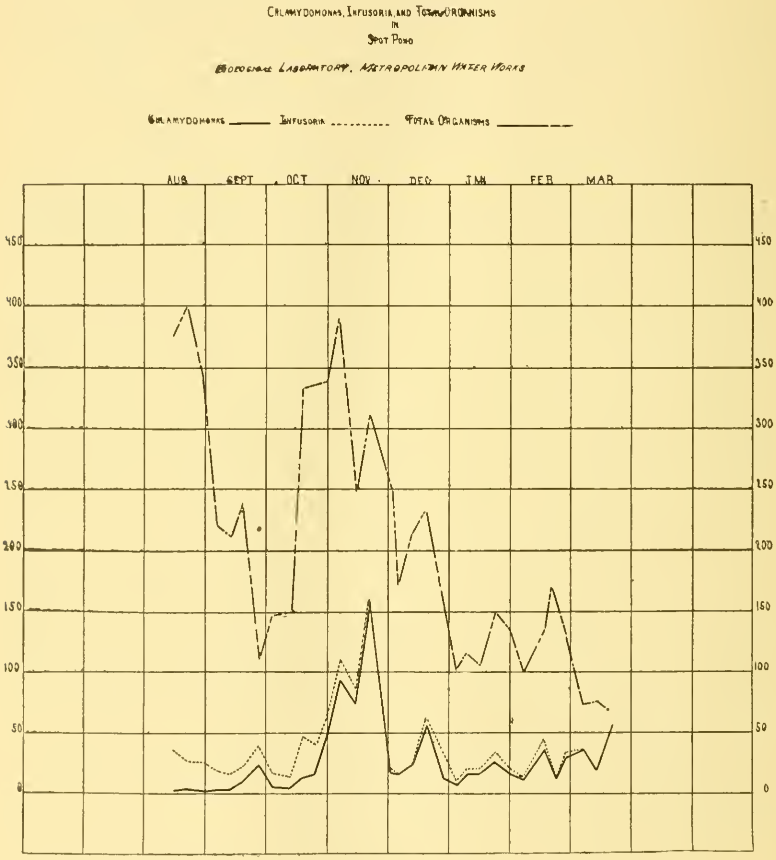
The growth of Chlamydomonas reached a maximum on November 21st, when they were present as follows:

	Number per c. c.	Standard Units per c. c.
Spot Pond—Surface	628	156
Mid-depth	682	171
Bottom	532	133
Average	614	153

Since then the growth has been confined mainly to the surface, and the average for all depths has risen only on one occasion

above fifty standard units per c. c., the average being about twenty-five standard units per c. c.

The relation between the total organisms, total infusoria and Chlamydomonas, as shown by the average for surface, mid-depth and bottom, is given on the following diagram:

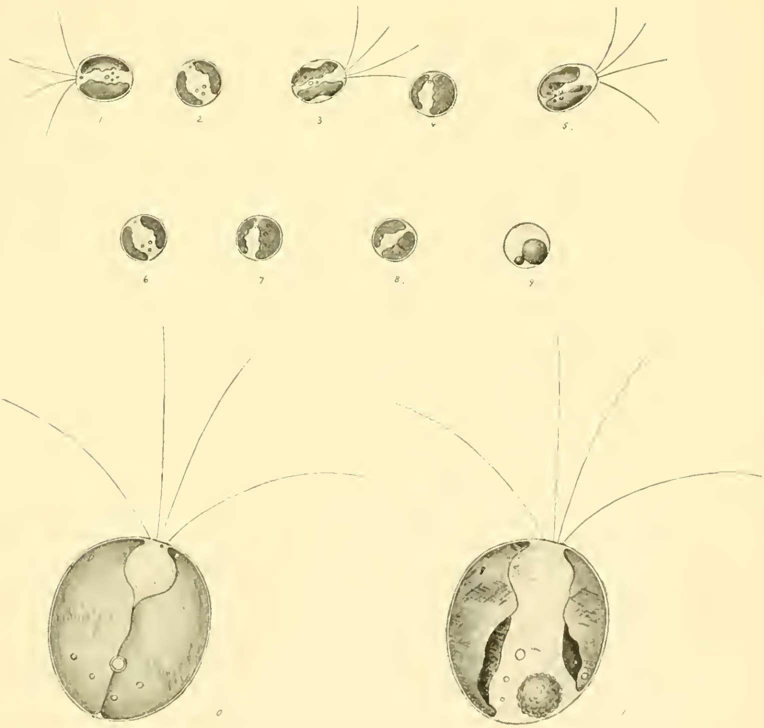


The form Chlamydomonas belongs to the class of flagellate infusoria. It was discovered by Ehrenberg in 1833 and described in 1838 in his "Infusions Thierschen" under the name of Chlamydomonas pulvisculus.

The study of the growth in Spot Pond was commenced in No-

CHLAMYDOMONAS. SPOT POND.

BIOLOGICAL LABORATORY, METROPOLITAN WATER WORKS.



vember, when measurements and drawings were first made. It is an ovoid form, having long diameter about 14 microns and short diameter about 12 microns, although different individuals vary in length by from 2 to 3 microns. It is characterized by the presence of a divided chromatophore enclosed in a lorica, although at times the portions of the chromatophos appear to be nearly fused together, and the separate parts are indicated only by an indentation toward the flagellate end (fig. 10). In other cases the individuals show the chromatophore separated far apart throughout the entire length, (fig. 11) which is undoubledly the condition preceding incistment or formation of the resting stage. The different phases of the division and arrangement of the chromatophore are shown by the small figures on the plate. Two, three and four flagella have been observed on the different individuals studied, but when three were observed, they were generally so placed as to indicate that a fourth was originally present. The contractile vacuole is situated in the clear portion at the flagellate end, and the nucleus, which is not always well defined, beyond the middle from this end. A red eye-spot is situated in the forward portion of the chromatophore, but is not seen in all individuals. Pyrenoids, described as starch grains, and clear globules, undoubtedly of oil, are present to the extent of from two to eight, arranged about the chromatophore, beyond the nucleus. The formation of the ripe zygote or final resting stage has not yet been observed beyond a doubt in this growth. The form observed in Spot Pond varies in some respects from that described by Ehrenberg. In the condition in which the chromatophore is divided, this form resembles the variety alboviridis of [1]Bütschli and of [2]Blochmann and, in some of its phases, it agrees with several of the nine forms given more recently by [3]Goroshankin as species. By watching from day to day the development of the organism, it seems not unlikely that many of the forms heretofore described as species represent different stages of development of the same organism. With the present state of our knowledge of the form, we would prefer to designate it as the Chlamydomonas of Ehrenberg.

1. O. Bütschli. Brown H. G. Klassen und Ordnungen des Thier Reichs Leipzig.
2. Kirschner und Blochmann. Thierwele ahl. 1. Protozoa Hamburg, 1895.
3. Proceedings of the Society of Natural History of Moscow, 1891.

DISCUSSION.

THE PRESIDENT. Professor Sedgwick, will you say something to us on this subject?

PROF. SEDGWICK. I really don't know enough about it, Mr. President, to discuss it. We have had such a feast of novelties in the papers presented by the gentlemen who have come after me that it seems almost too much of a good thing. I cannot help wishing we had spread them out a little thinner, and had one paper at each meeting, perhaps; but, after all, it is very nice to have such an abundance.

I think what Mr. Hollis has said about the food material in Spot Pond is rather surprising, and it seems to me that the organism of which he speaks, or almost any other, might get all the food it wanted there. I should like to ask him if any bacterial determinations have been made?

MR. HOLLIS. Very few have been made, not enough to give us reliable averages. The five or six determinations that have been made during the past year show comparatively low numbers of bacteria; from 100 to 300 per c. c. in the pond water, and lower numbers in service pipes supplied from this source.

PROF. SEDGWICK. It seems to me that the time is coming when we have got to take up, in connection with other organisms, the ordinary water bacteria as vehicles of food. There is no question that some of these infusoria feed upon the bacteria, and there is no doubt that the bodies of the bacteria furnish food for other organisms. Now that we are getting down to a real study of the food supply of organisms in reservoirs and trying to eliminate it, we cannot much longer neglect systematic bacterial examinations as to numbers and as to kinds. That has never been carried out at great length in Massachusetts. It has been undertaken in Ohio and in Connecticut, I think to some extent, perhaps in other states more or less. It is the most difficult and unsatisfactory part of the whole problem in a way, because bacteria are so small, and because they do not occur when they ought to, and our methods are not what we wish they were; but, at the same time, from these papers that have been read this afternoon, from Mr. Jackson's valuable account of the possibility of eliminating the food for these organisms, provided we know what the food is, it seems to me we cannot much longer afford to neglect the bacteria as food carriers. Not that they are

disease germs, or anything of the kind, but they are one form of food for various organisms, and one form in which organic matter exists and scatters itself abroad. I believe that the next step in this whole subject is extended investigation on the line upon which Mr. Jackson and Mr. Whipple and Dr. Hollis and Mr. Parker are at work, adding every possible item of information in regard to the food elements, the phases in which the food exists, its quantitative and qualitative relations, and the like; and that many of these further developments have got to come from a more careful study of the bacteria.

RELATIVE APPLICABILITY OF SAND AND MECHANICAL FILTERS.*

BY GEORGE W. FULLER, CHIEF CHEMIST AND BACTERIOLOGIST, COMMISSIONERS OF WATER WORKS, CINCINNATI, OHIO.

Mr. President and Gentlemen of the New England Water Works Association: In the present state of the development of sanitary science there is clearly recognized by sanitarians the necessity of providing by municipal water departments and water companies a water supply which shall be practically free from disease germs, and which shall be satisfactory with regard to its appearance.

To discuss a proposition like this before men who are so familiar with this problem is of course out of the question; but, in passing, it is gratifying to note that as the years go by the public are showing a clearer appreciation of the situation, and more and more there is being made a study, especially in the west, of the task of procuring proper authority, and of taking other necessary steps in order that works leading to purification may be constructed. The water works official, as I look at these matters, has an important duty to perform in educating the public and in making them see this situation with all its consequences with regard to the health of the community. Among other duties of the water works official, in many cases at least, is the consideration as to the best method of purification applicable to the local water supply.

The problem of water purification is a broad one. This is of necessity so, owing to the wide variations in the geological formation and local conditions of the watersheds, resulting in marked variations in the composition of the different water supplies. To appreciate this more fully, consider, if you will for a moment, the wide variations in the composition of the river waters of this country. Here in New England we find streams, most of them short when compared with the western rivers, coming from the

* Stenographic report of Address made on Feb. 8, 1899.

granite hills, and not from limestone and clay formations; so that as they reach the cities they are normally free from those large amounts of silt and clay found in the west. They contain sewage in many cases, as is true of many western rivers, but they are radically different with regard to the matters suspended in the water from the larger streams in the west. There we find during the frequent and long-continued floods large amounts of silt, such as occasionally occur in the east, but less frequently and in smaller quantities; and in most instances there are uniformly present noticeable amounts of clay particles, which vary widely not only in size but quantity. Between these combinations of certain but varying amounts of silt, and of certain but varying amounts of clay, there is almost an endless series of different compositions of western waters, frequently varying day by day and hour by hour. To determine the best method of purifying these water supplies is not a simple matter in many instances; and, furthermore, it is rendered none the less perplexing by the fact that there are now before the attention of water works officials and engineers two well-known methods of water purification. To speak of these two methods in general terms is perhaps all that I shall be able to offer to you this afternoon.

The announcement of this meeting states or implies that we have for consideration the topic of filtration, dealing with sand filters and mechanical filters. At the outset I wish to modify somewhat the point of view implied therein, and point out further that it needs a system of purification, in a great many instances at least, to purify adequately a water supply. By that I mean that a filtration plant which would serve in a great many cases to purify properly a water supply, especially New England waters, would fail by itself, independent of the particular method of filtration adopted, when we pass to many of the waters of the west.

In these remarks I therefore wish to make use of the expression "system of purification." In this sense, the terms "sand filters" and "mechanical filters" become inadequate. In that section of the country where I have been engaged for several years on problems of water purification, it has been the custom to refer to these as the "English system of purification" and the "American system of purification." In some of the water supplies on the Ohio and Mississippi rivers there is first necessary a preliminary subsi-

dence in order to remove the grosser suspended particles. There is also necessary the use of a coagulant for the clay particles, forming them into masses of considerable relative size. Afterwards comes the question of filtration.

I desire to outline very briefly the scope of the work which has been done, and the evidence which is now available upon these two methods or systems. Taking first the English method, we find that it is now seventy years since an English filter was first constructed in London. Since 1829 a great many improvements have been introduced with regard to the construction and operation of the type of filters in use at that time. Their use has extended from England over on to the continent to many continental cities, and, where their water supplies are purified by this system, this method, speaking in general terms, has been a satisfactory one, giving a good quality of water under favorable conditions of construction and management, and at a reasonable cost.

So far as we are able to learn, the limitations of this system of purification in Europe, from evidence which is quite well defined, are comparatively small. There seems, however, to be some reason to believe, as one passes from the western portion of Europe towards the east and comes to that part of the continent where there is much more clay in the soil, as in the eastern part of Germany and in Russia, that there is encountered a class of waters where the effluent of the English type of filter, even where the water has been treated by preliminary subsidence, is so turbid, that in those places this method of purification is not thoroughly satisfactory. As one passes into Russia, there is some evidence which has been obtained in an informal manner, which shows that there may be very serious objections as to the applicability of this type of filters assisted by subsidence for the waters of the eastern portion of the continent of Europe.

All of you are doubtless familiar with the history of the English system of purification in this country. It was first studied carefully, as you well know, by the late Mr. Kirkwood, in connection with the water problems at St. Louis. The investigations of water problems here in Massachusetts, owing to the well known studies by the Massachusetts State Board of Health, have shown that for this particular class of waters, like the Merrimac River water, this method of purification is peculiarly applicable, and one which gives

satisfactory results under proper conditions of construction and of management of filters, and without preliminary treatment by subsistence.

Clarification of the water is necessary in many of the western streams. As one passes from the New England waters and the glacial drift formation, and comes to the limestone and clay formations, there is encountered a type of water much different from these New England streams, as we have already noted. Taking the Mississippi or the Ohio, there is found a river made up of a large number of tributaries, which drain geological formations more or less unlike in character and represent territory in which the glacial drift formation is a comparatively small portion of its area, perhaps in some instances entirely lacking. The result of this is that, when the heavy rains come, there is obtained a water in these large streams which is very variable in composition, carrying at times of freshets enormous quantities of silt and of clay. The character of these clay particles is quite surprising to those who have never studied them. It is found upon careful examination that their size is very small indeed. In fact, they are less than one-tenth of the size of the bacteria; that is, many of them are not more than one one-hundred thousandth of an inch in diameter.

To purify a water of this class is an entirely different proposition than to purify a water such as that of the Merrimac River. That of course is due to a number of reasons; and obviously it is due in part if not principally to the immense number of minute clay particles. We find, as the evidence steadily accumulates with regard to the applicability of the English system to American water supplies, that there are limitations to it. There are limitations in two directions. In the first place, there is the marked turbidity, in the treatment of clay-bearing waters during freshets, of the effluent of English filters, and from the English system of purification involving therein a preliminary treatment of the water by subsidence to the limit of economy. The second point in which the English type of filter is not wholly satisfactory refers to the question of the deep penetration of these clay particles into the sand layer. It is obvious that the second of these limitations leads to more expensive conditions in the operation of these filters, involving deeper and more frequent scrapings in many instances than is normally the case

abroad, and in all probability to the reconstruction of the sand layer down to the underdrains at more frequent intervals.

Relative to the limitations to the applicability of the English system of purification, they have been known in a general way for many years. At the time that Mr. Kirdwood's book was published, now some thirty years ago, the evidence was almost entirely lacking; but it is said that he made some experiments, after the publication of his book, in which he encountered some of these difficulties, but under conditions and to a degree which are not very clearly known. He especially found out the difficulty in removing the clay particles by the English type of filtration, following the subsidence of the water and the removal of the grosser particles. This point, so far as I am able to learn, was first mentioned in the literature on the subject by the late Prof. William Ripley Nichols, in the annual report of the Massachusetts State Board of Health for 1874. In an article in that report, he pointed out clearly the difficulties which were encountered, not here in New England, but elsewhere, in getting a clear effluent from clay-bearing waters by this system. The question of the deep penetration of the clay, with its complications with regard to the operation of the filter, and especially the more difficult and expensive handling of the sand layers with regard to scraping and renewal, was demonstrated first at Louisville by Mr. Hermany, chief engineer of the water company there, by experiments conducted for about eight months during 1884–85.

The question of getting a satisfactory effluent by the English type of filter in the case of silt and clay-bearing waters after a preliminary treatment and removal of the grosser particles has been studied at Cincinnati. In fact, during the last year this question has been looked into with perhaps more care than anywhere else up to this time so far as it relates to river waters carrying large quantities of minute clay particles for comparatively long periods at a time. There have been investigated a large number of conditions associated with the construction and operation of filters, and involving studies of some fifteen experimental filters, which were described in Engineering News during last December. I will not take your time to go into the details already known to you. It is sufficient to state that very early in that work there was found a confirmation of the statements as to the limitations in the applicability of the English system of purification in western waters, where conditions as you

have noted are very different from those which have been encountered here in these New England waters, especially as they have been studied at Lawrence in connection with the Merrimac River. Furthermore it was found that when the effluents continued to be very turbid for some time the bacterial efficiency becomes reduced.

The causes of the limitations in the applicability of this type of procedure are not as well understood as might be. Primarily it is due in part to the minuteness of the clay particles. There are a number of supplementary theories in explanation of it. We find, for instance, as one of the probable factors among others in explaining why the clay passes through the filters and interferes with the scraping and operation of the filters, that it is largely due, so far as we can learn, to the absence of organic matter which forms a coating, more or less gelatinous in its nature, at the top and upper portion of the sand layers. In the western waters, the organic matter is not probably so great in amount as in eastern streams. I mean those portions of it which are capable of uniting with the sand grains and forming a gelatinous coating, and thus making conditions favorable for the retention of bacteria and of the minute clay particles in suspension which penetrate and pass through the sand layer. Those organic portions of the constituents of the water seem to be not only less marked in western than in eastern waters; but at times of freshets, when the need of this action in the English filters is greatest, it appears to be most lacking then, and practically speaking, almost absent. We find, in operating English filters on the Ohio River water, that the organic matter in the water is so stable for the most part that it is not readily converted into the form of nitrates, although the conditions favoring nitrification exist there. This was proven very clearly by the fact that after the filters had been temporarily stopped for some time, there was marked evidence of nitrification in the first portion of effluent when the filters were placed in operation again. The process does take place, but so slowly that it becomes eliminated from the factors of practical significance, because the organic matter contained in the water is very stable. The probable reason why the unstable portion of the organic matter in the Ohio River water —such as we find in the Merrimac River water, and which is desired in the filter to form this gelatinous film at the surface—is largely removed, is on account of its becoming attached to a con-

siderable degree to the sand and silt of the river water, which are eliminated largely by subsidence in the stream itself and in the subsiding basins. Thus it is removed before the water reaches the filters.

The problem of finding an applicable method for those western waters is one which involves a more comprehensive study of this problem of purification than is true in many localities; and in the course of the work at Cincinnati it was found necessary to make studies of several preliminary procedures in the system of purification, of which the English filters formed the last step. To do this there was instituted during the summer, after the experiments had been under way for some three or four months, a departure substantially as follows: The water was taken at the entrance of the experimental works in practically the same condition as it left the river, and subjected to a preliminary subsidence for about three days, in which the grosser particles were removed; and then at the times of freshets, when the amount of clay was very large, there was added to the subsided water a coagulant to get the remaining clay particles massed together, in such sizes and of such specific gravity, so that they could be subsided quite readily. By a coagulant is meant any chemical capable of aggregating clay particles into masses of relatively large size. Sulphate of alumina was used in the tests spoken of. This system, known in Cincinnati as the modified English system consisted, therefore, of a preliminary subsidence of the river water, then the application of a coagulant to the subsided water at times of freshets, and provisions for the supplementary subsidence of the coagulated particles, and finally the application of the water thus treated and clarified to the English type of filter. This process, or system of purification, has been one of the important lines of investigation at Cincinnati in connection with the purification of the Ohio River water for the new water supply of that city. This effort to make the English system of purification applicable not only to the fairly clear waters of the east, but also to the clay bearing streams of the west, is one which, so far as I know, has been looked into carefully there for the first time. The matter of making the English system applicable to all types of water is one which involves, of course, factors of costs; and they in turn are dependent very largely upon the frequency with which the heavy freshets occur, causing the water

to be laden with large amounts of silt and clay. It is these circumstances, among others, which makes a knowledge of local conditions an important if not indispensable element in the practical study and satisfactory solution of all problems in connection with the English system as well as the American system of purification.

Before taking up the question of the relative applicability of these two systems of purification, I shall touch briefly upon the American system. As you well know, this system of purification is one of American origin, and one which is perhaps better known to you as the method of mechanical filtration. In all cases the application of a coagulating chemical is required before the water is filtered rapidly through sand; and in many cases subsidence is necessary as a preliminary procedure. It has been called the American system of purification by many, and perhaps that term is less confusing on the whole. However, I am not here to advocate that nomenclature for others. It is the one which I use for convenience and explicitness. The American system of purification, having its origin largely in connection with industrial enterprises for the clarification of waters, is one which now has received somewhat careful study in a few localities, especially in connection with the clay bearing streams. Experience with such waters shows that the American system is capable of yielding an effluent satisfactory with regard to appearance and bacterial contents, and owing to the carbonates of lime and magnesia in waters coming from limestone regions, there is no probability of danger from undecomposed chemical (sulphate of alumina) passing into the filtered water when the operation of a plant is in the hands of competent persons. As many clay bearing waters require, in connection with the English type of filtration, a coagulant at times for the further clarification of the water before such filters become applicable in this connection, the popular and ordinarily unfounded prejudice against the use of chemicals is common to both systems.

While the English filter is peculiarly applicable to the waters of New England, which are free from clay, and which possess organic matter to form a gelatinous film, these waters in the west, carrying large amounts of clay, and sufficient alkaline compounds in solution, are more adapted to the process of the American system of purification, which is peculiarly applicable to them, as compared with either English filters or the English system of purification. That

is so, not only with regard to obtaining a clear and satisfactory effluent, but also with regard to the economy, under ordinary local conditions, there. Comparing the American and modified English systems for western waters, both are applicable, because it is necessary in those clay bearing streams to apply a coagulant in the preliminary treatment of the water independent of the style of filtration. The cost of purification approximates the same in these two methods, but the higher rate of filtration with the American method apparently makes it somewhat more economical.

With regard to the applicability of the American system of purification to those waters which are free of clay, that is a matter on which I am not able to speak in very definite terms ; and, so far as my knowledge goes, the evidence is not very well defined along some important lines. This is especially so with regard to the amount of sulphate of alumina necessary to be added in the preliminary treatment of the water prior to filtration, and with reference to the available alkaline compounds to decompose this chemical. Those matters are ones which to my mind will require further study in connection with the clear waters of this section. Whether it will be ever found that the American system is the more applicable for the clear waters of the east is a question remaining for the future. But, in general terms, the present indications are against it. To speak of it in specific terms, of course, at the present time is practically impossible owing to the great influence which is exerted upon the various factors by the local conditions, by the cost of the filters themselves, and other factors involving the questions of the size of the plant and the management thereof.

Speaking of the two systems of purification—to sum up in a very few words, what may be used perhaps as a basis for a discussion by the gentleman following me, and bearing directly upon the subject of these remarks—it is my belief that with those non-clay bearing waters, such as are found in the New England States, the English system of purification, or as a rule English filters independent of the subsiding reservoirs, are the more applicable ; and wherever the cost is equal or cheaper, with proper construction and operations, the English system of purification is unquestionably the superior. There are, on the other hand, in the far west those clay bearing streams where the amount of clay and the frequency and duration of freshets are such that the American system of purifica-

tion is not only somewhat cheaper—that varying, of course, under local conditions and with the intensity and frequency of the freshets—but it is also a system capable of more easy management than is the case with the English system when it is necessary to use a chemical in connection therewith. That is to say, the American system is managed with more ease than the modified English system which I have outlined to you very briefly in connection with the Cincinnati investigations.

Now between these two extreme types, with the fairly clear waters of the Atlantic sea board on the one hand, and those clay-bearing streams of the far west on the other, there is a large number of streams which carry clay for a small portion of the year, and perhaps only in small amounts at any time. Between those two types, there are a great many possibilities as to the composition of the water. It looks to me as though for many of those streams either one of the two methods would be found capable of purifying the water in a satisfactory manner. And the more applicable one will be chosen only after a careful study of the local conditions, especially of the river water itself with regard to the amount of suspended matter carried by it, the variations in those amounts in different portions of the year, and the character of the suspended matter, especially in connection with the cost of preliminary procedures which have for their purpose the preparation of the water to a degree where it can be successfully filtered.

Taking up the question of filters proper, independent of the system of purification involving coagulation and subsidence, it is my belief that at the present time the science and art of filtration, so far as it relates to the English filter and to the American filter, has reached such a point that there is no longer reason for hesitancy in our opinion with regard to their practicability.

As I look at these matters, the question of selecting a suitable system of purification for any municipal water supply involves for the most part a study of that particular supply in question, and especially the preliminary procedures which may be required prior to filtration proper. In some instances, no preliminary procedures will be needed, in others, both preliminary subsidence and coagulation, and even supplementary subsidence may be necessary. To decide upon a system, which has for its preliminary portions of the process such devices and such conditions that they will be adequate

at all times to prepare the water for filtration, and, on the other hand, not to get devices and preliminary procedures which shall be too expensive, seems to me to be where the real problem comes in the future in connection with the introduction of systems of water purification. Of course, here in New England, where a majority of the members of this Association live and are connected with water departments, the problems are very much less difficult than they are in those clay-bearing regions where the streams carry large quantities of clay such as I have been speaking to you about at some length.

The question of the management of systems of purification is a point about which I wish to speak a few words. I believe, as a result of my experience, that there is no municipal system of purification, no matter how uniform the composition of the water may be, nor how apparently simple in operation may be the system of purification, I believe there is no system of purification which can be managed to advantage by any other than skilled persons. By that, I do not mean necessarily the expert, but one who understands the local conditions, and is able to meet the various exigencies which are bound to arise. I believe that for the safety of the community such a procedure, that is to say, an efficient management of the plant is absolutely necessary, and that with any system of purification without it, it is questionable whether it is justifiable to expend large sums of money, and still have it an open question whether at all times the system of purification can be depended upon. As you pass from the simple systems of purification, such as are required in this section where the variations in the character of the streams are comparatively small, to those rivers of the central west where the variations are very marked, the question of efficient management is even more important; and it can be stated in unqualified terms that no system of purification can be made applicable to those waters unless it be under the management of skilled persons. The management of such works by skilled persons is not such an expensive matter, because with their knowledge of such affairs, it is possible for them to save money in many ways. Where coagulants are to be used, it is so easy to put in excessive amounts in the purification of large supplies, it is very probable that the most skilled manager that it is possible to get would really prove in the end to be the cheapest.

In concluding the brief comparisons in connection with these two methods or systems, the question of making a preliminary study of the particular water supply, and of getting properly adjusted in the system of purification those procedures which are required, if at all, to put the river water in such a condition that it may be satisfactorily filtered, and to manage the system as well as to construct it in an efficient manner, I believe to be the most essential features with regard to successful water purification.

I wish to thank you gentlemen, for your attention in listening to these few remarks.

DISCUSSION.

MR. ALLEN HAZEN, New York City. *Mr. President and Fellow Members of the New England Water Works Association:* I have a report of progress to make today, and I am glad to say that the progress has been substantial. It has come through the work of such men as Mr. Fuller, who has just spoken to us of the interesting experiments which he has been making; of Mr. Clark, who was to have been with us today, but who is unfortunately detained; of Mr. Knowles, of Pittsburg, who is not here, and of Mr. Copeland, who is here, backed up by the most valuable experience of other members of the Association who have filter plants in their charge, and who are able to secure results of the highest importance.

The progress which can be reported today is the solution of two of the most difficult and important questions which have required attention in connection with filtration, namely, the bacterial efficiency of mechanical filters at high rates and with the use of coagulent, and the adaptability of sand filters without coagulant to the treatment of extremely muddy waters.

As Mr. Fuller has told us, sand filters have been used in England and in this country for a certain class of waters for many years and with the greatest success. We have known for a long time that these filters could be depended upon to remove the bacteria or disease producing qualities of water with certainty. They have not been used extensively for the filtration of extremely turbid waters, and we have not known how far they could be depended upon in removing these excessive turbidities, especially from the waters of the larger rivers of the Middle States, which are entirely different in their character from most of the waters which have been so treated.

As Mr. Fuller has told us, mechanical filters have been developed almost entirely in America. They have achieved an obvious and signal success in removing turbidities from muddy Western waters. There has been but little information regarding the bacterial efficiencies which could be obtained from these filters, and especially as to the results which could be obtained in removing the disease producing qualities from sewage polluted but comparatively clear waters. Some light was thrown upon this question by experiments of Mr. Weston at Providence some years ago, and more recently by some experiments at Lorain, Ohio, but these experiments were very limited in comparison with those which have been carried out at Louisville, at Pittsburg and at Cincinnati, the results of which have been, or are about to be published, and which have formed the basis of the statements which Mr. Fuller has made to us today.

As a result of these experiments, and of observations which have been collected from various sources, there is now a large amount of adequate and reliable data which will allow many questions to be solved with confidence, which until now have been most perplexing. As Mr. Fuller has told us, for the clearer waters of the New England states, and of the states bordering upon the Atlantic coast, sand filters are much more efficient, and are also often more economical than mechanical filters. The removal of bacteria by them is more complete and more certain in every way than the removal of bacteria by mechanical filters. On the other hand, with the extremely muddy waters which are found in other parts of the United States, the clarification which can be secured by mechanical filters, with the aid of sulphate of alumina is more complete than can possibly be obtained by any system of filtration without the use of coagulant.

The range in the character of the waters in different parts of the country is very great. Mr. Fuller has told us something about it. I think it might be put even more strongly than he has stated it. With the waters of New England I think it is safe to say that the average suspended matters do not form 1 part in 100,000 of the water by weight. In many streams there are much less than that amount. That would cover the suspended matters in the Merrimac, and perhaps approximately those in the Hudson. The water of the Alleghany River at Pittsburg carries an average of 4 or 5 parts of suspended matters in 100,000, and at Cincinnati Mr. Fuller tells

me that the suspended matters are 20 or 25 parts in 100,000, and at Louisville 35 parts. That is to say, the Ohio River at Louisville carries more than thirty times as much suspended matter as the ordinary river waters of New England.

Mr. Fuller has examined the suspended matter microscopically, and finds that it is, in considerable measure, made up of particles not more than an hundred thousandth of an inch in diameter, or not more than one-tenth of the average size of water bacteria. One can readily see that the processes which remove these clay particles to best advantage may be quite different from those best adapted to the removal of bacteria. The clay particles are not only smaller, but they differ in other respects. The bacteria have the power of sticking together, and of sticking to the sand particles, and in filtration they are held back in this way. The clay particles apparently have not that power, and to remove them successfully they must first be gathered together into aggregates and removed as such. This is the first condition of the successful treatment of very turbid waters. It is accomplished by the use of sulphate of alumina or other coagulant, and after it is accomplished the water can be filtered either by sand filters or mechanical filters. The essential thing to be borne in mind is that it is necessary to coagulate the particles and to remove them as aggregates instead of as individuals.

A very important point to be borne in mind in determining upon the treatment of a river water is that the character of the water in the same stream often fluctuates to an enormous extent from day to day, and sometimes from hour to hour.

In studying this question we have found a record of the turbidity of the water most useful. The turbidity of a water is determined by taking a small platinum wire, fastening it into a stick and putting it into the water of the stream, pushing it down as far as the wire can be seen and noting the depth. The turbidity is then recorded as 1 divided by the number of inches at which the wire can be seen. The wire used is 0.04 of an inch in diameter, and must be kept bright. Observations are best taken in the middle of the day and in the open air, in no case under a roof, and not in direct sunlight. The stick can be graduated directly with the proper scale, so that the turbidity can be read from it without computation.

The process is very simple, and can be put into the hands of engineers at pumping stations, or of watchmen, and observations

can be taken which are reliable, and which allow good comparisons to be made of the character of water at different times and at different places.

In small streams, flowing from water-sheds which yield clay freely, the turbidity may increase a hundred fold in the course of an hour. That is to say, the water of a stream which had a turbidity of 0.02 before a summer shower, may have a turbidity of 2.00 directly afterward. Where the wire could be seen for 50 inches before the storm it can only be seen half an inch after the storm. These fluctations, especially in small streams, are very rapid, and it thus happens that a process which is best adapted for a given water part of the time is not suited for the treatment of water from the same source for the rest of the time, and it is necessary to change the method of procedure, or else to adopt means which will avoid the use of the most turbid waters.

This brings us back to the old English practice, as old at least as filtration, of having storage reservoirs to carry the water works by periods of excessive turbidity without drawing from the stream. With small streams this is practicable and advantageous. The periods of turbidity are usually of short duration, and the water between them is comparatively clear. A reservoir used in this way will result in securing a raw water for filtration freer from suspended matters than can be secured by any practical amount of sedimentation. The improvement in the average quality of the water which can be secured in this way is very great. This procedure has been used to a limited extent in American water works, and much more extensively in England. I feel strongly that there is room for a much more extended application of it in this country.

The cause of turbidity in streams is principally the action of sharp rains upon ground under cultivation. A water which flows from grassy or wooded areas is comparative clear. The turbidity of the water from a plowed clayey field is something enormous. The water in any water course results in a mixture of the most turbid waters from the cultivated land and the clearer waters from other land, and its character depends largely upon the condition of the water-shed from which it flows. Generally speaking, turbid waters are produced only during heavy rain storms. At other times small streams are always comparatively clear.

When the turbidity is once in a water it usually follows it down to the mouth of the stream. So far as I can find, the removal of turbidity by sedimentation in streams hardly exists except in cases where there are large lakes through which the water passes. On the other hand, the erosion of the stream bed rarely exists to such an extent as to increase materially the turbidity.

Of course it is true that rivers are picking up and moving about the sediment in their beds, but the matters thus moved are not to be confused with turbidity. The particles which figure in these movements are larger than those which constitute turbidity, and such matters will be removed from the water by even the shortest sedimentation, and have no influence whatever upon the treatment necessary for its clarification.

The length of time during which the water of a stream remains turbid appears to be in direct proportion to the length of the stream, and in a general way, the duration of turbidity is approximately equal to the time required for water from the most remote feeders of a stream to reach the intake at the rate of flow which exists during a moderate flood. If the stream is of such length that the water from the most remote feeders will arrive at the intake in 24 hours, then the ordinary period of turbidity will be about one day, and will occur as often as there are heavy rains, or once in ten or fifteen or twenty days. If the stream is twice as long, the ordinary period of turbid water will be increased to about 48 hours, but the frequency of turbid periods will remain as before.

As the length of the stream increases the length of the turbid periods also increases, until, when the stream becomes so long that the time required for the water to flow to the intake from the most remote feeders reaches the average length of time between rains, the mixing becomes so complete as to give very long or practically continuous turbid periods.

This results in the curious fact, that other things being equal, the longer a river the more turbid the water seems to be. Generally speaking, a water is most turbid when the volume of flow is greatest, and in a river receiving many tributaries, the character of the tributaries bringing in the most water, and therefore in general the most turbid, is a controlling element in the character of the mixed water. With tributaries so distributed that their flood waters reach the intake successively, the turbid periods are increased in length,

and although the whole of the water is no more turbid than the water of the individual feeders, the water taken for water works purposes becomes constantly more turbid as the size of the stream increases. It is probably largely for this reason that the water taken for water works purposes from the Ohio at Louisville has more suspended matter than that taken from the same stream at Cincinnati and very much more than at Pittsburg.

This has an important bearing upon the use of storage reservoirs to carry water works by turbid periods. With short streams the advantage of such reservoirs is most marked. With larger streams the turbid periods become longer, and the clear water periods between them shorter, until a point is reached where it is no longer possible to pump sufficient comparatively clear water in the intervening periods, and to store it to supply the demand during the turbid periods. The waters of large streams are thus more difficult to treat, and the improvement which can be effected by means of reservoirs is less. The problem of filtration thus becomes doubly difficult.

One of the most interesting experiments mentioned by Mr. Fuller is that of filters upon what he calls the modified English type, or what I should call sand filters operated with the occasional use of coagulant, the coagulant being employed when the raw water is particularly bad. By this process full advantage is taken of the wonderful power of bacterial removal of sand filters, a power which is independent of the use of coagulant, and which cannot exist in the more rapid mechanical filters, and at the same time full advantage is taken of the clarifying power of sulphate of alumina at such times as the condition of the water renders it necessary. This process I think opens up a most promising field. I do not know that any works have been constructed upon this basis as yet, except that it has been used to a limited extent in some of the Dutch water works. It should be cheaper in operation under many circumstances than mechanical filtration because sulphate of alumina is only required during the turbid periods, which are often but a small fraction of the total length of time; while it has the advantage of greater certainty of bacterial purification which the sand filters possess, and without their disadvantage of being unable to cope with extremely muddy waters.

The whole matter as developed by the recent experiments may be briefly summed up as follows: Mechanical filters with sufficient sulphate of alumina quantities are able to effect very fair bacterial purification, but sand filters are decidedly superior in this respect, and are also more economical where the raw water is not too turbid and other conditions are favorable. Sand filters are able to completely clarify moderately turbid waters, but with the most turbid waters of many of our rivers, they are inadequate and fail to yield effluents of the necessary clearness. For such waters satisfactory work can only be obtained with the use of some form of coagulent, and water so coagulated may be applied to either sand or mechanical filters, as may be best for the existing conditions. In any case, a raw water with as good a character as possible should be applied to the filters, whether sand or mechanical, and to this end preliminary processes of sedimentation, storage, and, where necessary, coagulation should be developed to their economical limits in all cases.

NOTE. Following, a number of lantern slides showing plans and photographs of a number of American and European filter plants were shown.

THE PRESIDENT. Mr. FitzGerald has consented to say a few words upon this subject, and show a few lantern slides.

MR. FITZGERALD. Mr. President and Gentlemen. At the request of the President, I came here to say a few words about one or two of the plants built by the city of Boston for the filtration of water. What I shall say is entirely without preparation, and I hope you will pardon any shortcomings. I am sorry to say that Mr. Clark has been taken sick, and I have come here simply to take his place. I have been very much interested in Mr. Hazen's remarks; and I was very sorry that I was not able to be here in time to hear Mr. Fuller. I have recently come from the south, and can appreciate what Mr. Hazen says with regard to the turbidity of the rivers there. Within a few days I was called to examine an aqueduct which was built to carry river water. In the morning the water was comparatively clear, but while I was gone to get a rubber suit and some rubber boots, a rain came up, and when I returned to go into the aqueduct, it was about half full of muddy water. The color of the streams is very beautiful from the aesthetic, but hardly so from the water-works point of view. I can think of nothing nearer than a good orange color, when I look at the surface of southern rivers after a rain.

Our problems here in the east are very different from those of other parts of the country where mud and silt are carried by the water. The filter-beds at Pegan Brook and Hopkinton Reservoir are interesting in that they were constructed to filter water through the natural ground.

Pegan Brook, of unsavory fame, is one of the feeders of Lake Cochituate. When I first became acquainted with the Boston Water Works, this brook was running literally as black as your hat. I do not think I ever saw a filthier stream. Of course, the first work was to get all the drainage and sewage out of the brook; but even after that was done, the wash of the streets rendered the water of a character hardly desirable for a water supply, so that it was decided to filter it. The shores of the lake are of sand. In fact, almost all the land around Lake Cochituate is clear sand—all except the hills which are of unmodified drift. Framingham particularly is situated in what is called "The Great Sand Plain" by geologists. You can secure good mortar sand almost anywhere without any screening whatever. The preparation of the beds consisted in removing the surface soil and putting it into low embankments, and then pumping the water from Pegan Brook onto the stripped surfaces, and allowing it to percolate slowly down to the water-tables and so into the lake. Of course, beds formed in this way give the advantage of a large area at very small expense, and excellent filtration follows. We have five filter-beds. The area of the water-shed is about a square mile. The chemical analyses show that the albumnoid ammonia is decreased from .04 to practically .007.

In the case of the Hopkinton Reservoir, there are some interesting points. Just below the dam is a large area of gravel, which seemed to have been placed there by nature in the right position for purposes of filtration, and it simply required the removal of the top soil and putting it into embankments to form filter-beds. As you know, the water stored in our reservoirs has a color generally of, say, from .60 or .70 on our scale, and while the quality is excellent in every way, yet it is very desirable to get rid of the color. The area of the land was about twenty acres. Five beds have already been built, and three of them have been underdrained in order to increase the capacity of the beds.

Those who have had experience with underdraining know how very difficult it is to keep sand out of underdrains. I have seen them taken up again and again full of sand. It seems sometimes difficult to keep water out of drains, even if they are laid with cemented joints. The old-fashioned way was to put muslin around the joints. I thought I would try some new methods at Hopkinton, and tried three different methods of putting in the underdrains. One consisted of laying 12-inch split pipes, true to line and grade, and with cemented joints. Inside of these inverts 3-inch pipes were laid and covered with stones and gravel screened to form a filter. This material was arranged in three layers, putting, of course, the coarsest particles of the gravel directly over the smaller pipes, and then filling to the top of the 12-inch pipes with the finer material. The object of this invert was to prevent the water from washing sand into the underdrains from underneath. By this arrangement we had a continuous filter over the drains, so that no water can possibly get into the pipes without passing down through the filter. This has worked very well, and is an excellent way to lay them.

There is another way that Mr. Brooks designed, which we tried, and which also works well. This consisted in laying one pipe inside of another and breaking joints—a 3-inch pipe inside of a 6-inch pipe—and filling the space between these pipes with screened gravel stones about the size of a pea. It is somewhat difficult to get the filtering material into the pipes, and we had to devise special methods for doing it. The third way in which we laid the underdrains consisted in laying an invert of graded filtering gravel and then bedding the pipe. Over this was put an arch of filtering material. Each of the drains was thus covered with a continuous filter. This method also works quite well. I am at a loss to state which one of the three methods is the best. Time alone can tell, but I am partial to the first, laid with the split pipes.

There are many water works all over the country where this kind of construction is applicable, and can be put in at small cost. I do not think we resort often enough to filtration in water supply systems. My views have been expressed so many times in regard to the benefits of filtration that it is [not necessary to dwell upon them at this time.

In speaking of filtration, of course there are no rules which are applicable to all waters alike. I remember very well when the Lawrence experiments were first made, everyone thought that the intermittent system was to be the panacea for all woes; but in carrying on a continuous and intermittent filtration side by side for several years, I found that the continuous gave as good results for Boston water as the intermittent, and I suppose there is little doubt now, if water has plenty of oxygen in it, that it does not gain much by an intermittent over a continuous process. There are many places where water may be diverted from the bed of a stream to a gravel area and allowed to filter through the ground where the soil is of a suitable character for this purpose, and then collected.

NOTE. Mr. FitzGerald exhibited a number of lantern slides of sewage filter beds.

PROF. WILLIAM T. SEDGWICK. Mr. President and Gentlemen. I will take time to say one word. It seems to me that this Association is very much privileged to hear from two such masters of the art as Mr. Fuller, and Mr. Hazen, in one afternoon. I am sure those who have followed the development of the whole subject, as some of us have from the beginning in this country on a large practical scale, feel very much indebted to them for the work they have been doing, and the clear and admirable manner in which it has been presented. I could not help feeling as Mr. Fuller was speaking that, with our present knowledge with regard to water, his point is good, and that we should speak of purification in general, and not filtration.

Perhaps I may say we should speak of the treatment of water rather than purification, because sometimes it is not purification, from a sanitary point of view, but treatment, as for instance, the reduction of hardness. That does not concern us much in this part of the country, but we will hear later as to the difficulty of getting a good drinking water, on account of its hardness; and processes for water softening are coming into use, and the art of correcting this is reaching such a stage of development that we can no longer take raw water and give it to the community with impunity. Treatment may require additional means for getting rid of the turbidity, but finally we may need to soften the water, and as we go on, we shall very likely find that other steps may be required to be taken. To speak of the treatment of water, is such a complete revolution

from our old fashioned American point of view that it is quite noteworthy. It is not so long ago that water companies had only to stick a pipe down into a water course and take water out with impunity. Now we are not satisfied with this. The whole process is developing. Mr. Hazen spoke very truly when he said that he and Mr. Fuller were making a report of progress. I had hoped Mr. Copeland might be here to say something on the bacteriological side of this question, but the hour is so late there is hardly time. I think this Association should congratulate itself that it has had at its tables these men who have come out into the world, taking up new problems and solving them successfully. It seems to me that *distinguished* success and ability in life is not merely to do well things which have been already done, but to go to fresh fields and take up new problems and master them. Any one who has seen Mr. Fuller's volume, knows how masterly the work is. It ought to be a source of gratification to this Association that instead of going away from home to learn the news, the news comes to us, not through a reporter, but from the investigator himself, and that we have heard from Mr. Hazen's own lips of his magnificent work, showing throughout, good sense, skill in construction, and knowledge of bacteriological work. It seems to me that we, who have seen these young men develop into men of full years, and to full activity, may well be very proud. I, at any rate am proud, and I am sure the whole Association is. I have esteemed it a favor to have been able to listen to these men this afternoon, and to come in close contact with them. This is the work that tells, and will give to America a reputation in all our future work in this connection. I think the Association is honored by having heard from these gentlemen this afternoon.

ORGANISMS WHICH CAUSE UNPLEASANT ODORS AND TASTES IN WATER SUPPLIES.

BY PROF. W. T. SEDGWICK,

Professor of Biology, Massachusetts Institute of Technology.

[*Read March 8, 1899.*]

Mr. President and Fellow Members of the Association: Your committee or officers who had in charge the preparation of programs for your meetings this season, have taken large subjects, and have suggested in their notice in regard to them that they would be treated partly on the historical side, and partly on that side which may be called up-to-date. It seems to me best to start the subject of to-day at the beginning, treating what is ancient history, however, very lightly, and giving opportunity for those who are to come after me, and who are in the very thick of the fight, a chance to tell us the latest researches and developments in this particular line. I shall then play the part of what might be called the back number in a file of magazines, and undertake to bring the subject up to the time when the numbers shall be more fresh and interesting, and I promise not to detain you very long.

If a hole should be dug in the ground and filled with distilled water, the latter would almost immediately become, relatively speaking, impure. From the surrounding earth it would receive into solution certain organic and inorganic substances contained in the soil or sub-soil, and into suspension certain other materials derived from the same sources. From the air it would receive dust, rain or snow, and these all contain materials some of which would pass into solution, while others would remain in suspension.

Now, this is very much what happens in the genesis of public water supplies. Water distilled from the earth or sea passes as aqueous vapor over the land. It is condensed in the atmosphere as distilled water, and sooner or later falls upon the earth; but long before it has reached the earth it may have been contaminated

by dust, and even by the bodies of micro-organisms. Arriving upon the earth or upon bodies of water such as lakes or ponds, it brings with it, then, not only dissolved organic and inorganic matters, small in quantity, to be sure, but nevertheless real, but also the bodies of living and probably also of lifeless organisms, few in number in some cases, but by no means inconsiderable. Even at the very beginning of a supply of surface water, therefore, the conditions are favorable for the growth of organisms, for not only are these present in their actual living forms, but food also awaits them in the dissolved or suspended materials derived from the air or from the neighboring surface of the earth. The latter in particular contributes liberally to their support, because it is itself not only highly organic, but rich in microscopic life, and if the raindrop which falls into a reservoir has, as is usually the case, either flowed over the surface of the living earth for some distance or made its way a little distance within the living earth and then again to the surface, it has derived from these excursions, in connection with the rich stores of organic matter which they contain, material suitable for the support of innumerable micro-organisms.

It may not be known to all of you, but often rain and snow, probably even when formed very high in the atmosphere, are already contaminated; I do not mean infected, but that they often contain the bodies of micro-organisms. In fact, we know from physicists that a raindrop probably cannot form even in a high atmosphere unless it forms around a particle of dust. And what is dust? Dust is ordinarily pulverized earth. And what is earth? Why, it is the surface layer of this globe, which is generally heavily charged with living micro-organisms. A particle of dust, therefore, may contaminate or pollute, if you choose to use the word in the broad way, a raindrop or snowflake at the very instant of its birth, high in the atmosphere. Moreover, as the raindrop and snowflake filter down through the lower layers of the air, richer in micro-organisms than the upper air, they take up on the way living material. This is particularly true with snow. At the end of the big snowstorm of a month ago, we collected from the top of a building on Trinity Place, in the Back Bay, snow which presumably had fallen late in the storm, and therefore when the air was comparatively free from dust. Nevertheless that snow, when melted, yielded per cubic centimeter an average of 8 or 10 bacteria

—living bacteria. A snowflake, as you can see, as it comes zig-zagging down, is like a piece of cotton wool, and it naturally picks out of the atmosphere any dust particles which may be there. These living particles which are present are not necessarily wholly bacteria; occasionally microscopical organisms are found. So, also, rain, which as everybody knows often has a peculiar taste, may contain dust, and may be, as I say, impregnated at the start with the germs of life. Of course the moment it arrives on the earth it comes in contact with rich supplies of food, and with numerous other organisms than those it already contains. It is well known that when snow goes off in the spring it contributes to the rivers and the lakes vast numbers of micro-organisms; and every thirsty boy who has eaten snow knows that snow has a distinct *taste*, and that it isn't the flat taste of distilled water, but is, rather, a dirty taste in many cases; and in fact snow is very often dirty, especially in the early part of a snowstorm. And the same thing is true, of course, in a rain storm, though in less degree.

Now, my point is, that even if distilled water were to be put in a hole in the earth, it would almost immediately take up from the living earth, which is largely organic, both suspended and dissolved materials; the dissolved materials would be inorganic as well as organic, and thus food is prepared or made ready for the organisms almost at the very beginning of collection of water.

It has long been recognized that surface waters are apt to have peculiar tastes or odors. The terms "pondy," "vegetable," "fishy," "grassy" and the like, excite no surprise when applied to such waters, and it was doubtless the early recognition of these various tastes and odors, combined with the general flatness and the color of surface waters, and the liability of the latter to disappear when most needed, in times of drought, which led our ancestors to prefer and to depend upon ground water supplies, such as wells, for their drinking water. It remained, however, for the development of the microscope to make it possible for us to study satisfactorily the living population of a pond or lake, and it is a rather curious circumstance that it is only within a score of years that anything like a careful scientific examination of lakes and ponds has been begun. Such investigations arose from two sources: first, from the practical side as relating to the bearing of tastes and odors upon the quality of drinking waters; and, secondly, from the

purely scientific pursuits of biologists of the problems of microscopic life, and particularly embryology. On the former, the practical side, the State of Massachusetts was the first to begin. On the other, the more theoretical side, the work was begun by the Germans under Hensen, of Kiel.

It had long been the custom of embryologists to collect the microscopic life of the sea which swims at the surface by means of skimming-nets, the material thus collected containing, especially if taken at night, vast numbers of embryos suitable for the study of development. Hensen extended the idea of swimming embryos, hitherto known as the "pelagic" life of the sea, to include all forms of life capable of being caught by a fine net, and to such life gave the name of "plankton," a word derived from the Greek and meaning "wandering." The net in question was generally dragged over the side of a boat, and large amounts of water could thus be more or less perfectly filtered in a very short time. This method is not only of great interest in biology, but has been used by certain biologists for the examination of fresh water lakes with good results in this country, particularly in the case of Lake Mendota in Wisconsin, Lake St. Clair and Lake Michigan. It has not yet been applied to any great extent to the examination of water supplies. As a result of the immense development of biology which has taken place in the last twenty-five years, laboratories or stations for investigation have been established not only at various points on the sea, as at Penikese, by the elder Agassiz; Newport, by Mr. Alexander Agassiz; at Woods Hole, Massachusetts; Beaufort, North Carolina, and several points on the west coast of America; but also at numerous places on the Continent of Europe, and in one case, at least, in Japan. These in turn have given rise to fresh water biological stations for the study of the life of lakes and ponds, the first one dating from 1891. These stations, together with the physiological and chemical investigations of the lakes of Switzerland, have given rise to a new science, limnology, or the science of lakes, which deals not only with the lakes as physiological bodies, but also with their geology, their chemistry, their geography, their biology, their meteorology, and the like, and the relations of these to each other. In a series of lectures before the Lowell Institute, Professor George Darwin of Cambridge, England, dwelt at consid

erable length upon tidal phenomena in lakes, particularly as these have been worked out by Forel in Switzerland.

Quite apart, therefore, from all studies of lakes as sources of water supply, the last ten or fifteen years have witnessed an extraordinary development of our knowledge of lakes and ponds in various directions, so that if nothing had ever been done on the subject of lakes and ponds as water supplies, we should still be in possession of much valuable information in regard to them from the biological and limnological point of view.

As it happened, however, at the very same time when Hensen was developing his ideas of the plankton and the examination of the microscopic life of the sea by the methods just referred to, it became no less desirable to investigate the microscopic life of lakes and ponds used as sources of water supply, and in 1887 the State Board of Health of Massachusetts began their investigation of the inland waters of Massachusetts, which has constituted the basis of all investigations in America on this subject since that time. This work was at first in the hands of Mr. (now Dr.) G. H. Parker of the Museum of Comparative Zoology of Harvard University, and much valuable and interesting work was done under his direction. It became necessary for Mr. Parker to devise a method which should be somewhat quantitative, and he did this by tying a cotton cloth over the lower end of a glass tube through which the water could be filtered. For nearly two years this method was used in the work of the Board, after which it was superceded by an early form of what is now known as the "sand" method. The latter, with various improvements, has been used ever since; i. e., for about ten years, and Mr. Goodnough, who follows me, will give some idea of the results obtained by its use. It has also been employed in other States than Massachusetts, and in other investigations than those connected with the examination of water supplies—such, for example, as the study of the food of fishes by the late lamented Professor Peck of Williams College.

Since the last meeting of this Association there has been published by Mr. George C. Whipple, who is well known to us all as a graduate of the Massachusetts Institute of Technology, and as formerly Biologist to the Boston Water Works and the Water Works of Lynn, and now Biologist and Director of Mt. Prospect Laboratory, Department of Water Supply, Brooklyn, New York,

the most important volume on "The Microscopical Examination of Drinking Water" which has yet appeared in any country. A copy of this I have in my hand. The publication of this volume may be said to mark an epoch in the study of the organisms in water supplies which produce unpleasant tastes and odors. I desire to give a brief analysis of the book with a view of pointing out its fundamental importance, and in the hope that I may induce you all to buy it for your professional libraries. The author is entitled to much, at least, of recognition on the part of all who are really interested in the science of water supply, which, as you know, underlies its practical applications.

Many of you undoubtedly have seen the book. I say it is the most important book on the subject which has yet appeared. It is the only book which is in any respect whatever up to date. It is the only book in English on the subject since 1875. In that year a book entitled "The Microscopical Examination of Water" was published by J. D. Macdonald, an Englishman, but his method of examination of water was very defective. It consisted simply in collecting some sediment and looking at it. It cannot be called quantitative at all, and it was too primitive to be of very much value. It was an interesting episode in the development of the subject, but hardly anything more. This new book, prepared by Mr. Whipple, who was himself prepared by the work of the State Board of Health of Massachusetts, and that branch of it which has been followed up by the Boston Water Board, and who has been further prepared by most careful studies of his own, really constitutes a landmark in the development of our knowledge of the "Microscopy of Drinking Water," which is the title of the book. It is published by Wiley of New York.

Starting out with a description of the various methods which have been used in the examination of drinking water, the author goes on at once to the object of the microscopical examination, the interpretation of analyses, and the use of the microscopical examination in indicating sewage contamination, in explaining chemical analyses, in explaining and determining the odor and turbidity of waters, and incidentally in the studying of the food of fishes. He then enters into the details of the method described in and used throughout the book, namely, what I have called the "sand" method; points out the errors involved and compares it with other methods,

and concludes that for water works people it still remains the most useful method. That has been disputed by some and will be disputed by others. It is held, for example, by Prof. Kofoid of Illinois that the method is inaccurate to such an extent as to seriously invalidate its worth ; but Mr. Whipple, after having examined the various methods, on the whole concludes that it is still the most available at any rate for the purposes represented by the members of this Association. A rival method is, as I stated, the plankton method of dragging a net through a large amount of water and getting whatever is collected by the net. It is hardly necessary to say that in such a case a great many of the finer organisms escape, and a great many of them are crushed.

Mr. Whipple then takes up the subject of micro-organisms in water from different sources, rain water, ground water, river water, canals, and speaks of *Raphidomonas* in the Lynn water, pond water and the like. Next follows a chapter on limnology, which is written, it seems to me, with a good deal of discrimination. Mr. Whipple has read widely, is familiar with the investigations in Switzerland and elsewhere. He takes up the question of the diathermancy of water, its permeability to light and the like, the temperatures at various depths, the classification of lakes, the bleaching properties of colored waters in the light, turbidity, transparency. and so on—a very valuable chapter. If all the rest of the book were to be lost that chapter would still remain of great practical value to anyone in charge of a body of fresh water which is liable to vary in color—which is sure to vary in color if a surface water—and which is liable to be invaded by micro-organisms. He then takes up the geographical distribution of the latter and their seasonable distribution, points which are not yet clearly understood, by any means, and indicates with a great deal of care the things which are known, differentiating them from those which are unknown.

At length he comes to the subject of odors in water supplies, a subject to which he has given a great deal of study, and which he sums up, it seems to me, well. This Association will be interested to see it definitely stated in print that the famous cucumber odor of the Boston water in 1879 or 1880, which we very well remember was felt to be certainly due to sponge, was probably not due to sponge at all, but to *Synura*. Anyone who remembers the excite-

ment which the condition of the Boston water caused at that time, and the great satisfaction which was felt that the cause of the odor had been discovered, will now be interested to know, as many of course do know, that it was probably not really located at the time in the sponge, although the sponge occurred with it, but that is was *Synura* which gave rise to the odor.

The author takes up the storage of surface water, the storage of ground water, the growth of organisms in pipes, etc., speaking for instance of *Paludicella*. Here we find summed up the troubles in the service pipes in Hamburg and in Rotterdam; things which previously we have had to dig out the original papers are here put together in good shape, so that anyone can get at them quickly, and trace them to the original sources if he desires.

In other words, the first 150 pages or more of the book are a good digest of the present state of our knowledge. And when you reflect that this is the only practical book in the world on this subject, that it is the only book in English printed or professing to have anything to do with the subject since 1875, that it is the only book in the world which is at all adequate, you see how important it is. It brings the whole matter up to date as well, probably, as it is possible at present to do it, and it is, therefore, a very valuable work for all who are interested in water supplies.

As Americans, and especially as members of this Association, and many of us belonging in this State, where this whole science has really had its root and origin, we have reason to be proud, I think, of the orderly fashion in which our knowledge is now brought together.

A classification of the microscopic organisms and the description of the genera and species, so far as those are interesting to water works people next follows. A biologist might be disposed to criticise this part somewhat, but for practical purposes, and that is what the book is for, in large part the account seems to be very well done. At the end of the book are appendices with directions for practical work, tables, formulae, a very admirable bibliography, which is most valuable to anyone interested in the subject, and which on the whole I should say is carefully prepared; and at the end, a glossary. Finally, we have an index and a series of plates, which unfortunately are not colored, (to publish colored plates would be altogether too expensive) but they are soft in effect and

characteristic in draftmanship. They are carefully prepared and taken either from nature or from good authors, and they are certainly creditable. They represent, as any such plates must, a large amount of careful, painstaking work; and I hope that the time may come when the sale of this book and similar books will be so extensive that the publishers and author may see their way clear to provide colored plates, which would add very much to the beauty, at least, of the work, and I think also to its practical value for waterworks people.

In conclusion, I wish to bring your attention to the fundamental biological principles which underlie this subject. As I said at the beginning, if distilled water were to be poured into a shallow hole in the ground, or may I add, if it were to be emptied into a little depression of the surface, in which it could stand as surface waters do in reservoirs, it would not long remain as distilled water. From the earth and from the air it would collect a certain amount of dissolved and suspended matters and would become what we call a surface water. Among the matters thus collected would be active or inactive but yet living micro-organisms, the smallest of which, and probably in the first instance the most abundant of which, would be those microscopic forms which we call bacteria. Immediately the bacteria would begin to multiply upon the dissolved organic matters present, and upon the bacteria would very quickly be found feeding organisms for which they are acceptable food, especially infusoria. At the same time, certain microscopic plants, green in color, possessing chlorophyll and therefore endowed with the property of manufacturing organic out of inorganic matters, would probably make their appearance, and upon these or their products in the long run more infusoria might develop until the water was rather richly charged with life. Eventually forms would appear capable of feeding upon the infusoria, and others, always larger, in turn upon these, until fishes or other relatively huge but scarce organisms should feed upon them.

In other words, we have the cycle of life supported very simply in this way: first an extract of the earth or of dust or of air or of something containing dissolved and suspended organic and inorganic matters. Upon these dissolved matters, particularly upon the dissolved organic matters, those microposcopic forms which we call bacteria, and which are really scavengers seeking for such organic matters,

would feed and multiply. We start, then, from the organic and inorganic matter in solution, with the bacteria. These come in first—they convert the lifeless organic mattter over into living matters which are food for other living matters. But soon, if the water stands long enough, green plants may appear which are able to live upon the inorganic matters dissolved from the air and from the earth, and by virtue of sunlight, and through protoplasm and that mysterious substance which we call chlorophyll, in ways which we do not fully understand, but which we believe to be functions of portions of the spectrum of sunlight, these green plants are able to live upon the inorganic matters and build up organic matters. If they die, their bodies furnish food for more bacteria ; if they live, their bodies may furnish food for microscopic animals which feed upon them. So that given the bacteria at the bottom and the green plants alongside of them you may have more food materials built up which shall serve as food for other organisms, and others larger and larger in turn, until on the principle of the big fish eating up the little ones, we get up to the fishes.

Two things and only two evidently underlie these cycles, namely, first, organic matter in solution ; and second, sunlight. If either of these be excluded the life present must before very long come to an end. In the case of ground waters, it is possible by covering the reservoirs to prevent the development of any considerable quantity of life, unless the supply of dissolved organic matter be kept up, and this supply is usually very scarce in ground waters. For surface waters, on the other hand, exposed as they are to the sunlight, this plan is not practicable, and neither is it practicable to do away altogether with supplies of dissolved organic matter. This is because the living earth is so rich in organic matter that any surface water must of necessity contain dissolved organic matter. The best we can do in both cases is to reduce these two sources of trouble to their lowest terms ; which is aimed at in modern reservoir construction, first, by the process of stripping and, second, by securing as far as possible the absence of light by the use of deep rather than shallow reservoirs, though, of course, as soon as we do this we introduce other problems as to the water at the bottom of the reservoirs, which problems are familiar to you, and some of which are dwelt upon at length by Mr. Whipple in his book.

So far as the principles are concerned, this, then, is a very simple matter. When it comes to the application of these principles, as in the application of all pure science, the opportunities for variety are immense. The amounts of organic matter and the kinds of both living and lifeless organic matter in particular cases will be very variable. The amounts of sunlight will also be very variable. Therefore, the problems as to the population of the reservoir by microscopic organisms and the bacteria will also be various. Some of these will appear, I think, in the papers which are to follow.

DISCUSSION.

DR. HOLLIS. Prof. Sedgwick has spoken of the second method, known as the plankton method, which some advocate for use in the study of the micro organisms of a water supply. That is a subject to which I have given more or less thought, and I have studied many of the problems which have been worked out by that method, and it seems to me this would be a very good opportunity to say a word in regard to the two methods.

The study of a water supply is necessarily a practical one. These organisms generally grow, increase, at a certain depth or level, and a very large part of our work is in locating within quite narrow limits these growths, in order that the water drawn from the reservoir may be drawn in such a way as not to include the water containing the growths. This, we find, is best done by taking the samples from the surface, mid-depth and bottom. Frequently the growth is found near the surface, and in that case the water can be drawn from the other levels safely, ordinarily for some time; for a long period, before the organisms work their way down. Now, if the examination is made by the plankton method, we don't get an idea of the position of these organisms. The method consists in lowering down a net or drag, in all the cases about which I have read, and drawing it to the surface; collecting, in other words, the organisms in a column of water extending from the bottom to the surface at that point, and our count obtained in that way would be an average of the organisms at all depths. In that way we would gain no exact knowledge as to the position of the growth, and it would not be of the same value that the counts of samples taken at the surface, mid-depth and bottom would be.

SOME RESULTS OF THE SYSTEMATIC EXAMINATION OF THE WATER OF PUBLIC WATER SUPPLIES.

BY X. H. GOODNOUGH, CHIEF ENGINEER OF THE MASSACHUSETTS STATE BOARD OF HEALTH.

[*Read March 8, 1899.*]

The modern public water works, like many other great public services, is a thing of very recent growth. The first system of importance in this State was completed in 1848 for the supply of the city of Boston. Water was supplied by aqueduct companies in several other towns in the State previous to that time, but not in such abundance or under such pressure as would be deemed necessary at the present day. So that the modern system of water works dates from half a century ago. After the system for the supply of Boston was completed other cities and towns in the State began to follow the example of the chief city, but between 1850 and 1870 only 14 cities and towns in the State introduced public water supplies. Between 1870 and 1880, the growth was much more rapid and at the beginning of the latter year 64 of the cities and towns of the State were provided with public water supplies. At the present time the number of cities and towns supplied is 162 and they contain 90 per per cent. of the total population of the State. Only two towns having a population of more 3,500 are now not provided with public water works; while as many as 15, having a population of less than 1,500, are provided with such works. With the rapid increase in the demand for public water supplies and the increase in the number of works that began half a century ago, there came a demand for better information as to the quality of water and the study of the quality of public water supplies consequently received a greater degree of attention. The methods of water analysis in use when the introduction of water works first began were so crude that it is evident from an examination of the results of some of the chemical analyses of forty years ago that very little was shown by them in addition to

that which could have been learned by a physical examination of the water. New methods of analysis were in time discovered and the system used by Prof. Wm. R. Nichols in the laboratory of the Institute of Technology, in the early '70's, contained many of the prominent features of a water analysis of the present day. With the introduction of new methods of analysis, much additional information was furnished as to the quality of a water and it was practicable to make more satisfactory comparisons of the quality of different waters; but the number of sources under examination at any time was usually very small, and but few analyses were made, so that the results of the analyses were necessarily interpreted from a very limited experience, and it often happened that the significance of some of the various determinations was not appreciated.

A systematic examination of the waters of Massachusetts was begun in 1886 under an act of the Legislature giving general supervision and control of all inland waters to the State Board of Health, and directing the board to cause examinations of such waters to be made from time to time to ascertain whether they were adapted for use as sources of domestic water supplies, or in a condition likely to impair the interests of the public or imperil the public health. The examinations of the public water supplies and rivers of the State was begun in 1887, and have been carried on since the beginning under the direction of the engineering department of the board.

Careful studies of methods of analysis were first made with a view of selecting such methods and determinations as would show most satisfactorily the condition of a water. Improvements in the methods of analysis and additions to the number of determinations have been made from time to time when found necessary or desirable, but the original determinations were made with such accuracy that the results of the earlier years are directly comparable with those of today. It is therefore practicable by means of these analyses to study the condition of a large number of waters for a period of many years.

The investigation of the microscopical life existing in water developed gradually, like the chemical analysis, with the increase in the construction of public water works, but at the beginning of the investigations of the State Board of Health no satisfactory method of determining rapidly the number and kinds of organisms

in a given sample of water had been developed and the methods of analysis first used in these investigations were, in consequence of a lack of knowledge of the subject, crude and unsatisfactory. New methods of analysis were developed, however, by the biologist of the board, and for the last eight or nine years the method used for obtaining the microscopical condition of a water has not been materially changed.

Beginning in 1887 every system of water works in the State was examined by one of the engineers of the board and about 200 samples of water from as many different sources in all parts of the State were analyzed each month. The comparisons made practicable by these investigations and numerous analyses very soon showed several remarkable facts. Before the investigations were begun chemists had apparently discovered that the quantity of chlorine in a water bore some relation to the animal pollution of the water, but one of the most prominent facts observed early in the investigation was the great variation in the chlorine or salt contained in the waters from different parts of the State which came apparently from unpolluted sources. By tabulating the results of analyses it was soon found that there is a certain normal amount of salt in waters of this State, varying with the distance of the source from the seashore. The normal chlorine of unpolluted waters from the extreme western part of the State is as low as .05 of a part per 100,000, while that of unpolluted waters from sources near the seashore may be as high as 2.00 parts, or even more. A knowledge of the normal chlorine of the region from which a water is taken was therefore found to be essential to the proper interpretation of a chemical analysis.

Another prominent fact brought out by these analyses was the essential difference between a surface and a ground water, making it impracticable to judge of the quality of both in all respects from the same standpoint.

One of the most important facts shown by the earlier examinations was the deterioration of ground water when exposed to light. It was found that many of the ground waters when first drawn from the ground were clear, colorless and odorless and were practically free from organic matter, while these same waters after passing through an open reservoir were found to be turbid and offensive to taste and smell, and to contain often a large quantity of organic

matter. Microscopical examinations showed that the deterioration of the water was due to the presence of organisms in places where the water was exposed to light as in open reservoirs and filter basins. On the other hand, ground waters which were kept wholly from exposure to the light did not deteriorate at all in this way from the time they were drawn from the ground until they were delivered to the consumers. As a result of these studies it seemed evident that by keeping ground water from exposure to light, deterioration could be prevented. This conclusion has been borne out in numerous cases in which covered reservoirs have since been constructed to replace open reservoirs, and the results of the chemical and microscopical examinations have shown that water supplied from a covered reservoir remains of the same quality as when drawn from the ground.

Some ground waters which were found to be excellent when first examined have been found to deteriorate after several years of use. The principal evidence of such deterioration is the appearance of considerable quantities of organic matter and an excessive quantity of iron. Such waters are often clear and colorless when drawn from the ground, but quickly become turbid by oxidation of the iron when the water is exposed to the air. Such waters are objectionable for use in the laundry and for many other purposes on account of the iron they contain, and in some cases, sources furnishing such waters have been abandoned on this account. Such deterioration is generally found in sources drawn from ground containing organic matter in the soil such as deposits of river silt, or at places where there is a large depth of mud or similar organic matter on the surface, such as is often found in fresh water meadows. Deterioration from this cause has often been found in cases where a well or filter gallery is located very close to a body of surface water from which the supply is largely derived by filtration through the ground and appears to be due to the imperfect filtration of the water from the surface source. The condition of the iron found in the waters mentioned is not always the same. In many cases experiments made by the board have shown that it can be removed readily by filtration, but in some sources where the iron is associated with large quantities of organic matter its removal by filtration is difficult. Experiments have shown, however, that it is practicable to purify such waters and make them entirely satisfactory without using pro-

cesses that will render the water objectionable by increasing its hardness or by injuring its quality in any other way.

The information gained by experience in the investigation of many such cases has made it practicable in most cases to avoid the selection of sources exposed to danger of such deterioration.

The danger involved in the use of water taken directly from sewage polluted rivers, even though the source of pollution was located a long distance above the place where the water was taken, was also clearly proven by these and other investigations and in many places large sums of money have been expended in the construction of new works to secure a pure water at places where waters from such sources had been in use.

The examinations of brooks and rivers showed a great variation in the quality of water from such sources. Some of them were clear and colorless and contained but little organic matter, while others were deeply colored and contained usually a large quantity of dissolved organic matter. The highly colored waters flowed mostly from swampy districts and the color and organic matter were found to be largely due to the slow passage of water through swamps where it remained for a considerable time in contact with vegetable matter.

The examination of the water of ponds and reservoirs early showed great variations in the quantity of organic matter present in the different sources, and in some ponds or reservoirs there were often great variations in the quantity of organic matter in the course of a single year. The early investigations indicated that the waters of some ponds and reservoirs were apparently satisfactory at all times. Others were found to cause complaint occasionally, while in still others the quality of the water was frequently bad at certain seasons of the year. Microscopical examinations of the waters showed that where complaint was made as to the taste and odor of the water there was generally present a large number of organisms, frequently largely of a single species, and it was often found that the taste and odor of the water was probably due to the presence of the organisms. As a result of the investigations, it was found that certain organisms almost invariably cause certain tastes and odors when present in a water in sufficient numbers, while others give little or no odor to a water even where present in large numbers. In some ponds and reservoirs, the number of organisms found has always been small,

and the water of such sources has very rarely had a disagreeable odor, but it must be said that in the course of our examinations a large proportion of all ponds and reservoirs examined have been found at some time to be affected by the presence of large numbers of organisms or by a disagreeable taste or odor. It is not practicable within the space that can be devoted to this paper to present more than a very general statement as to the various water supplies that have been affected at times by excessive growths of organisms or disagreeable tastes and odors, or as to the organisms which have been found to cause such troubles.

Careful studies of organisms present in various surface waters have shown that there is in general a regular seasonal distribution, certain organisms being present in greatest abundance in certain seasons of the year. Anabæna, for instance, is seldom found in large numbers except in the late summer and early fall, and so far as I have been able to observe has seldom occurred in sufficient numbers in the colder portion of the year to cause serious trouble. Certain of the Infusoria, on the other hand, apparently grow in abundance only in the winter season. One of the most notable of these, and the organism which, when present in large numbers, probably causes more serious offence than any other which we have thus far observed in the water supplies of the State, is the organism Uroglena. It was first observed in March, 1892, when it occurred in very great abundance in the water supply of the town of Plymouth. Complaint as to the offensive character of the water at this time led to an examination by the board, by which it was found that a very large number of organisms of large size were present in abundance just under the ice of Little South Pond, close to the intake. The organisms were so large that they could readily be seen with a naked eye. The water in the distributing system at this time was characterized by a very offensive fishy or oily odor, but only very few of the organisms could be found after the water left the pond, and practically none were discovered in the distributing system. They apparently went to pieces after entering the pipes, but it was found that the organism contained an oil which evidently became diffused in the water and which was the cause of the disagreeable taste and odor.

Altogether this organism has been observed at different times in 44 ponds and storage reservoirs in the State; in some cases only

at one time and in very small numbers, and in other cases during several winters and in great abundance, making the water exceedingly offensive to taste and smell. It has also been observed in three open distributing reservoirs which are supplied with ground water. As already stated, this organism occurs very largely in the winter season from December to March or April, and is practically never found in the months of July, August or September and rarely in the months of June and October.

While the number and variety of microscopical organisms found in surface water is very great, our investigations indicate that many of these organisms are present only in very small numbers at any time, and only comparatively few of them, even when present in great numbers, are, at present at least, thought to be capable of rendering water disagreeable for drinking, but some of these few, notably those previously mentioned, Uroglena and Anabaena, have been the cause of very serious troubles in public water supplies. While a water company or water department supplying a city or town is not often exposed to direct competition in the business of distributing water, it is, nevertheless, true that other things being equal a water that is clear and colorless and free from taste or odor is far more acceptable to consumers and is capable of producing a larger net income for the works than one which is turbid and colored, or which is at times disagreeable to taste and smell. When a water which is usually of good quality suddenly becomes offensive to taste and smell, it appears from experience that serious injury to the income of the department may result. While it is pretty difficult to measure the extent of injury that may result to a water company or water department from a condition of its water which causes it to become offensive to consumers, I have heard of at least one case where a water department has found it desirable to make a reduction in the water bills on account of the fact that the water delivered to consumers became very offensive to taste and smell and remained so for a period of many weeks. The rebate in this case is said to have been as much as one quarter of the water rates, resulting in a direct loss of between $2,000 and $2,500 of the income of the works for the year. It should be added, that in this case the quality of the water was probably more objectionable than had been known before.

While this case gives a measure of the direct loss that may occur

to a water department as the result of an offensive condition of the water, there may also be an indirect loss to the inhabitants of the town in such cases, because the water of the public water supply being offensive for drinking the inhabitants generally resort to other sources of supply and much money is often expended in the purchase of spring waters. Nor does this expense fall upon those who can bear it best, because many instances have been found where the operatives of factories subscribe money for the purchase of spring water for drinking purposes in the factory in the summer season. Moreover, it appears that in those towns which are supplied with water which is always acceptable for drinking, little or no spring water is sold or used.

The question as to how to prevent water from becoming disagreeable from bad tastes and odors and as to the purification of waters which, while perhaps usually free from taste or odor, are objectionable on account of a high color and the large quantity of organic matter which some of them contain, has been carefully studied since the beginning and a large amount of information bearing upon the improvement of such waters has been obtained. The presentation of such facts as have been obtained and the discussion of their bearing upon the question of the improvement of such water supplies are considerably beyond the scope of this paper, but some of the more important points that have been brought out by a systematic examination of many waters under many and various conditions may be referred to.

In the case of ground waters, as already indicated, the deterioration of the water from these causes can be prevented by keeping the water from exposure to light and with such sources the cost of covering places where the water is exposed to light, such as filter basins and reservoirs, is not a very serious matter, but in the case of large surface water supplies taken from ponds or storage reservoirs, storing the water in the dark is impracticable and some other means of preventing tastes and odors in the water caused by the presence of organisms or otherwise must be devised.

With regard to the cause of the appearance of microscopical organisms in water, or the means preventing their appearance, very little is yet known. They appear in excessive numbers generally at irregular intervals, and without any apparent cause. The results of examinations for the past twelve years have shown that very few

ponds and reservoirs are at all times free from an excessive growth of such organisms. Experience seems to indicate that they are dependent upon a food supply found either in the bottom of the reservoir or in the water which enters it.

Storage reservoirs constructed in connection with the earlier works generally received little preparation for the purpose other than the removal of the vegetable matter above the surface of the ground, such as trees and brush, and these sources have generally furnished water of the poorest quality. It was supposed that the water of such sources would improve after the organic matter became dissolved out of the ground. In some cases improvement has apparently taken place in the water of such reservoirs; in other cases, however, no improvement was observable after several years of use. Examinations of samples of water collected from the surface and bottom of many storage reservoirs and natural ponds made possible a comparison of the quality of the water in each at various depths and these results showed that in some ponds and reservoirs the water of the bottom was very foul in the summer season, while in others its quality was about the same as at the surface. These investigations, together with observations of the temperature of the water of several lakes and ponds at various depths in the summer of 1889, showed that the water in the deep ponds and reservoirs remained stagnant at the bottom during the summer season and that in many of them there was a large quantity of decomposing organic matter in the water of the stagnant layers. With the cooling of the water at the surface in the fall this matter was distributed by the circulation of the water from top to bottom through all the water of the reservoir and in cases where there was much organic matter in the stagnant layers, the quantity of organic matter in the water near the surface of the pond was greatly increased in the latter part of October or early in November.

Continuing the temperature observations through the following year, it was found that there was another period of stagnation in the winter season and a second short period in the spring when the water circulated freely from top to bottom. In this connection, it may be of interest to quote from a report of Dr. C. T. Jackson, a chemist, employed to investigate the cause of a "cucumber taste" in the water of Lake Cochituate. The investigations were appar-

ently made in November of the year 1854, or about forty-four years ago:

"We visited all parts of the lake, tasted of the water at every tributary lake and stream, and that drawn by a hose from various depths in the lake. We found the surface water free from any unpleasant taste. * * * *

"Water drawn from a lower depth had that peculiar flavor which we find in the aqueduct water in Boston, and this taste was strongest at the depth of from 19 to 39 feet from the surface. * * * *

"We all agreed in opinion that the taste resembled that of water in which cucumbers had been soaked. * * * *

"The temperature of the water at the gate house was 43½°, that of the air being 53°. At the bottom of the lake the thermometer stood at 44°, hence the water at the bottom of the lake is a little warmer than that of the surface. The records of the superintendent of the lake show, that during the month of July last the temperature of the water was, in the gate house, 73° F. * * *

"We rode all around the country that is drained into Cochituate Lake, and tasted of every streamlet or collection of water, and did not observe in any of those waters that peculiar flavor which we had found in the deep water of Lake Cochituate. It would seem, therefore, that either the bad tasting stratum of water had entered the lake some time since, or that it has derived its peculiar taste from fermenting vegetable matters at its bottom. If the bottom water had become charged with a vegetable infusion during the heat of summer and autumn it could not rise to the surface until the top water was cooled down to such a degree as to render it denser than the water below, so as to descend and displace it. The maximum density of water is at 39.2° F., while the water at the gate house has been 78° in July and August, and is now at the bottom 44°. It is evident that if the surface water during cold nights should descend to 39.2°, that it would descend and displace the lower strata of water, and cause them to rise. This would take place at less differences of temperature at slower rates, exactly proportioned to the differences of temperature, provided the upper strata should be coldest; but the reverse could not take place, hence warm water does not descend to replace cold water, unless the temperature of the lower water should be considerable below 39.2°,

when it would be lighter, as may be seen from the following table. * * * *

"It is well known that the bad taste of Cochituate Lake water came on soon after the sudden cold weather of the middle and latter part of the month of October, and perhaps this sudden change of temperature may account for the rising of the lower strata of water, so as to cause them to run into the conduits. * * *"

In the construction of a new reservoir by the Boston Water Works in 1886, the plan was tried of removing all the soil and vegetable matter from its bottom. This reservoir was completed just before the general examination of water supplies by the State Board of Health was begun, and samples of its water, collected from the bottom as well as the surface, have been analyzed at regular intervals for many years. In this reservoir and in a few natural ponds, it was found that no decomposition took place in the bottom in periods of stagnation, and in the water of these sources, also, it very seldom happens that any considerable growths or organisms are found. In more recent years, it has been the general custom in constructing storage reservoirs to remove the soil and organic matter from the bottom, and where this work is thoroughly done and the water entering the reservoir is of good quality, and is not made up largely of ground water, it has thus far been found that the water of such reservoirs has contained but few organisms and is apparently not affected by disagreeable tastes or odors. In one case, where the most favorable site for a reservoir contained a swamp having a depth of mud of many feet, the removal of which would have been very costly, the plan was tried of covering the mud with gravel to a depth of 18 inches. The quality of the water of this reservoir has been excellent during the few years that it has been in use.

These and other studies indicate that the removal of all the soil, mud and vegetable matter from the bottom of a storage reservoir makes the water stored therein in a large degree unsuitable for the high development of microscopical organisms. The results of certain other investigations give evidence that the water of reservoirs can be rendered even more unfavorable as places of development of large numbers of organisms if in cases where the brooks and streams which enter them contain large quantities of organic matter, improvements in the channels or water sheds of the brooks could be

made which would reduce materially the quantity of organic matter in the water. In this state, the brook waters which contain large quantities of organic matter usually acquire the organic matter from standing in swamps. If it is feasible to drain a swamp thoroughly and prevent water from the uplands from entering it, the water flowing from the watershed in which the swamp is located can be greatly improved. The extent to which the improvement of a swamp by drainage may improve the quality of the water of a stream may be indicated by presenting the results of analyses of one such case, where a swamp occupying about 12 per cent. of the area of a watershed was drained in such a way that the water flowing from the uplands was intercepted before entering the swamp and the water flowing upon the swamp was quickly removed by ditches carefully constructed for the purpose. The average results of several analyses taken before and after the construction of these drains is shown in the following table :

Color.	Total Res.	Loss on Ignition.	Ammonia,		Oxygen Consumed.	
			Free.	Albuminoid.		
1.76	5.12	2.90	.0017	.0329	1.502	Before Drainage.
0.24	3.19	1.14	.0007	.0099	0.303	After Drainage

In connection with the analysis of samples of water from ponds and reservoirs at various depths, the water of the principal feeders of such sources was also examined and upon comparing the results it was found that in the reservoirs and ponds of the better class, while the water flowing into them had, in some cases, a high color and contained a very large quantity of organic matter, the water flowing out of them had less color and organic matter, showing that it had improved by standing in the reservoir.

Since storage reservoirs are usually constructed some time before they are actually needed, it is generally feasible to prepare them properly for the storage of water, but it generally happens that after the use of such reservoirs is begun it is not practicable to empty them and go without the water for a season without providing other means for supplying the city or town. In the case of a natural pond, also, it is of course generally impracticable to empty it and remove any organic accumulations from its bottom and while it is

possible that in the case of some ponds and reservoirs an improvement of the watershed may have a sufficiently favorable influence upon the quality of the water to prevent further serious trouble from tastes and odors, it may often happen that improvement in the water cannot be effected in this way.

The problem of preventing such waters from becoming offensive to consumers from time to time is a serious one, since there is a considerable number of such sources. It is possible that some means may be discovered for the prevention of organic growths in such sources, but no way of preventing such troubles is known at the present time. It is probable that such waters can be filtered in such a manner as to remove the organisms and odor without injuring its quality in other respects, and considerable information has been obtained as to the filtration of such waters and further investigations are under way.

The question is often asked as to whether waters containing large numbers of microscopical organisms, or which are offensive to taste and smell, probably on account of the presence of such organisms, are likely to be injurious to the health of those who may drink the water. With our present information on this subject, we can only say that it is not known that the presence of these organisms, or any of them, in water renders it injurious to health. The well-known fact that some of the higher plants, such as ivy and dogwood, while injuring some persons who handle them, yet have no effect upon others, suggests the possibility that a similar influence may be exercised by some of these organisms upon some of the persons who drink water containing them. Even more suggestive is the well-known fact that some fruits and vegetables, such as strawberries and mushrooms are so injurious to some people that they find it necessary to avoid their use. It is also well-known that eating decayed fruits and vegetables is very dangerous in the summer season, and it is suggested that drinking water containing decayed organisms may possibly have a similar effect. A further suggestion that these organisms may be injurious, is found in the obscure epidemics of diarrhoeal diseases that occur in the summer season when large numbers of people are sometimes attacked at the same time, while the people of another community nearby may not be effected. It will naturally be extremely difficult to determine whether the organic matter in the form of

microscopical organisms in water has an unfavorable influence upon the health of those who drink the water; and it must be remembered in this connection that very few people will drink water that is offensive or even slightly odorous, but will rather go to the expense of purchasing other waters.

As a result of the systematic examinations for many years, our knowledge of the conditions which effect the quality of all kinds of public water supplies has been greatly increased. It was natural that many important discoveries were made within two or three years after the work began, but new and very important facts have been learned from time to time, and our examinations reveal more clearly than ever the great need of further definite information upon many points. They show, also, that the regular examination of public water supplies is even more important than was suspected in the beginning. And it is probable that in the future further knowledge upon this subject will be obtained which will be at least as important as the information already acquired.

DISCUSSION.

PROF. SEDGWICK. I would like to say just one word in justice to Mr. Richards, Superintendent of the New London water supply: Before this meeting began he was telling of a case exactly similar to that which Mr. Goodnough has pointed out, where by the intercepting of the water from a watershed on its way to a swamp he was able to avoid a large amount of color, which the water would have had if it had gone through the swamp. The expedient which he adopted, seemed to me so interesting I urged him to bring it up at some future meeting of the Association, when we have experience talks, and it seems to me it would be well worth doing. As Mr. Goodnough has said, it is a simple and a very useful and effective plan, in some cases at any rate, to drain the swamp in order to prevent the standing of the water there, and in other cases to intercept the water, which would go to the center of the swamp and perhaps stand there, before it has a chance to do so; thus preventing it from ever becoming colored. The case which Mr. Goodnough has mentioned is ample testimony to the value of the practice. Mr. Richards has done this in the case of an additional supply to his New London reservoir, and with admirable results, he says; and it seems to me this is an

interesting and timely point in connection with Mr. Goodnough's valuable paper.

In regard to *Uroglena*, I cannot help calling the attention of the Association to the fact that in this connection the investigations of practical water works men have thrown great light on the theoretical side of the subject. When *Uroglena* was first detected or reported, it was found in Middletown, Connecticut, by Prof. Conn, of Wesleyan University, who did not at first recognize what it was, and thought it was another organism. That was in June, 1889, if I remember right. A little later than that it was found by Prof. Williston, in a reservoir, only a few miles away, in Meriden, Connecticut; and then it was found in great quantities as Mr. Goodnough has said, in Massachusetts, and was thought to be a novelty in both States. It has now been found in, I think he said, 44 supplies of this State. In other words, now that we have looked for it, and have had systematic examinations of the water supplies, we find that instead of its being a rare and unusual thing, it is really a pretty common thing. Formerly those who made a specialty of keeping track of the microscopical organisms from a purely microscopical point of view had not even reported it in this country. I remember looking for it at the time in a list published by some expert on the subject of Infusoria, and not finding it.

So that here practical work has developed very interesting scientific truth, as so often happens. There is no contest between pure science and practical science, between pure and applied science, and never can be. Each helps the other. Pure science gives us points for practical work; practical science reacts and stimulates the study of pure science. One has only to turn to electricity to see the exemplification of this law. It seems to me that in *Uroglena* we have also a very interesting example of it, and a very valuable one.

It ought to be a matter of pride to members of this Association that many of them have been able to follow the actual steps of progress made in this direction from year to year. And nowhere in the United States, I think we may say without boasting, and indeed nowhere in the world, has the examination been carried on so systematically. Mr. Goodnough has made a very good point there. At the start it was urged by the wise physicians and engineers who were on our Board of Health, that these examinations should be

extensive, that they should be *systematic*, that they should be *long-continued*. They have been all of these. And Mr. Goodnough testifies, and we all testify, that we to-day realize more than we ever did before the importance of keeping them up and making them thorough, for out of these researches come practical results of immense value to any one dealing with the subject.

MR. PARKER. While we are speaking of this organism, Uroglena, I should like to tell the Association a little experience I had. Some years ago I had occasion to inspect a large reservoir, which was connected with a system of other reservoirs, in reference to a particular subject. After completing that inspection I made my report to the superintendent, and three days later I went out to the reservoir to see how matters were progressing. To my surprise and astonishment I found I had an entirely new and more important problem on my hands. In that period of three days an immense growth of Uroglena had developed in the reservoir. I made a hasty examination of the reservoir, and immediately went back to Boston, and from there to the superintendent to whom I was to report. As I went into the room he was giving orders to draw water from this infected reservoir. I think if that had been done the whole supply of the city, which I had temporarily in my charge then, would have been ruined; I think for at least a period of three months it would have been impossible to have given the citizens good water.

That shows the importance of this work, and it also shows the importance of field work. It is not enough to have samples come to the laboratory. We must have the laboratory supplemented by field work, and by the observation of practical men who have the water in charge. Any man who has a reservoir, by training himself to look out for the sediment, and especially the change in color, may very often be able to give very valuable information to those in charge of the laboratory.

And in connection with this same subject, I might say that this system of reservoirs was so arranged that we could cut out this contaminated reservoir from the system and draw from the others. Now it seems to me that is a valuable point. There are a great many, or at least several towns in New England that do not depend on the supply from one point or from one body of water. They have two or three bodies of water. And if those towns employed a biologist to tell them at what depth in their ponds to draw, and

when to draw from certain ponds, all the citizens would be very greatly benefited. It isn't such an expensive matter to employ a biologist, and I think it is for the superintendents here to call the attention of the city fathers to the fact that there are towns in the State that have biologists, and to suggest it to them if it would not be well for them to employ such a man in connection with their supplies. That is one of the practical results which I think has come out of the magnificent work which has been done by the State Board of Health.

Mr. Haskell. Mr. President, I have had the opportunity to have charge of water works where we did have an opportunity to observe our water, and to draw from the source in which the water was the best. We have a laboratory, and we examine our water every week. We find there is no difficulty in telling beforehand when a certain organism is preparing to show itself. We find that it is just as readily discovered as it is to see a crop of clover grow in a clover field or oats in an oat field. And we have been able at different times to draw water from one pond, and then perhaps from another, when a personal observation of the water at the point would not have led us to make that choice. I have gathered a sample of water, and to all appearances, as I looked into it, it was the best water that we had, but the analysis showed that there was an organism preparing to develop; and in another pond, where the water looked even better, there was an organism which was disintegrating and was disappearing. So we would change, and by making the change we would get better water. And the only possible way by which we could have got the information which led us to make the change was the microscopical examination. It could not have been determined by personal observation, either by taste or smell, which of the two waters was the one which should be taken. Nobody can tell by personal observation; there must be a microscopical examination. And we have been able to give better water from year to year by having our laboratory, and understanding the proper way to detect where the organisms were going to develop; and we often change right in the middle of the week from one pond to another, neither of which is necessarily bad, but one of which is better than the other.

A FEW WORDS UPON WATER FILTRATION.

BY H. W. CLARK, CHEMIST, STATE BOARD OF HEALTH OF MASSACHUSETTS.

[*Read Feb. 8, 1899.*]

After the very interesting papers by Mr. Hazen and Mr. Fuller upon the subject of water filtration, it is rather difficult for one, whose experience with filtration has been limited to New England waters, to present anything particularly new. Yet New England experiences with New England water supplies are the experiences of most of the members of this Association, and when the water supply in which any one of you is most interested arrives at the point where filtration becomes a necessity, or is desirable, most of you will undoubtedly prefer to filter it in the tried and proved way of slow sand filtration, the method that has been for so many years in successful and satisfactory operation in England, on the Continent and at Lawrence, Mass.

Unfortunately, in one way, nearly all of the New England data upon the subject of sand filtration has been obtained at Lawrence from the experimental filters at the State Board of Health Station, and the large filter belonging to the city. The results from all these Lawrence filters are published yearly in the reports of the State Board of Health, together with more or less of the details in regard to their management.

It was found during the first years of investigation at Lawrence, that the highly polluted water of the Merrimac River could be filtered through loam and sand at a comparatively low rate and practically all the bacteria of the applied water removed. Following this, experiments were made to ascertain if water as polluted as this river water, could be filtered at rates great enough to make sand filtration practicable in connection with town and city water supplies and at the same time render the filtered water safe for domestic purposes.

These investigations were carried on with great care and thoroughness, and were continued long enough to render the results obtained of much value when applied to New England water supplies, or water supplies resembling those of New England. As a result of them, the Lawrence city filter was constructed in 1893, and even the most doubting person should be convinced of its efficiency at the present time, for here is an example of a city smitten with typhoid fever epidemics yearly when using unfiltered water that has been practically free from the disease since filtered water was introduced.

The death rate from typhoid fever at Lawrence has decreased steadily each year up to the end of 1898, since the introduction of this filtered water. It is true, as was remarked upon by a city government and water works delegation who visited us at Lawrence a short time ago, that this decrease began before the construction of the filter, but in answer to this it can be said that for a year or two previous to filtered water being supplied to the inhabitants of the city, the dangerous character of the water supplied directly from the Merrimac River was known to the more intelligent of the people, both because of their own observations and because of warning notices from the State Board of Health. Consequently, the sale of spring waters was a large and growing business in the city, the city water was in many families boiled before using, and one of the large mill corporations had constructed and had in operation for a year or two a sand filter large enough to furnish pure, well filtered water to all the operatives in its mills.

The death rate of the city in 1892 from typhoid fever, however, was 10.52 per 10,000 inhabitants—this year being the last entire year that unfiltered water was used, and the death rate from typhoid fever the lowest for many years up to that time. During the past year, 1898, the death rate from typhoid fever was 1.39 per 10,000 inhabitants, that is, there were only eight deaths in the city from this disease, including several mill operatives who were exposed at least to infection from the unfiltered canal water supplied for various purposes in many of the mills.

The rate of filtration of the city filter rarely if ever exceeds 2,000,000 gallons per acre daily. In regard to the rate of filtration that can be maintained by sand filters and still result in pro-

ducing a safe drinking water, I think that too much attention has been given to European ideas and rules regulating the rate and not enough to the character of the water to be filtered in particular cases. That is, the degree of pollution of the water chemically and bacterially, its percentage of dissolved oxigen, etc. This is a point I think that we are learning more about each year and broad statements made in Lawrence reports in earlier years we would wish to qualify to some slight degree at the present time and limit their application to certain waters and certain conditions. Thus, in the 1895 report I stated that "the longer the investigations upon water filtration continued the more evident it became that the entirely satisfactory bacterial purification of water could be obtained at rates of filtration much greater than formerly supposed. Entirely satisfactory results being obtained during 1895 from filters operating at rates of 5,000.000 and even 7,000,000 gallons per acre daily." These results, I should say at the present time, were satisfactory when bacterial efficiency alone is considered, that is, the percentage of bacteria of all kinds removed from the Merrimac River water by the filters. Four filters were operated at these high rates for definite periods, and 99.50 per cent. of the bacteria of the applied water were removed. Of course, these were experimental filters, and were handled probably more carefully than filters on a larger scale could be handled, but at the same time, there were some things in their construction which were likely to render the results obtained from them less satisfactory than from filters of a larger area. For instance, the side area of the experimental filters is much greater when compared to the superficial area than is the case with larger filters, and it has always been noticed at the station, and referred to many times in our reports, that there is a tendency at times of change of temperature for a channel to be formed between the sand and the straight sides of the experimental filters, down which some water occasionally passes to the underdrains without having passed through much, if any, of the sand.

But perhaps, as our further work tends to show, some things must be taken into consideration besides the actual percentage of bacteria of all kinds removed when we are talking about satisfactory and efficient filtration; especially so when we are dealing with a water as polluted as that flowing in the Merrimac river at Lawrence.

During the past year or two, besides the determination of the total number of bacteria present in the river water and the filtered water from the various experimental filters and from the Lawrence city filter, many determinations have been made to show the presence or absence from these waters of B. coli communis, the characteristic bacteria of sewage. This work has been undertaken to show, if possible, if bacterial efficiency, as we have designated it, meaning the percentage removal of bacteria of all kinds is directly comparable at all seasons of the year with the percentage removal of this sewage bacteria. We have believed that by the continuation of this work for sufficient time the significance of the appearance of this germ in filtered water can be determined, because of the opportunity presented of studying the full results obtained with regard to its presence in samples of filtered city water taken from various points upon the city system, together with the occurrence or non-occurrence of typhoid fever in the city. These bacterial results from the city filter we can also compare directly with the results from the experimental filters at the station operating at different rates, but receiving the same polluted river water. In doing this work we of course assume that the absence of B. coli from the filtered water is an unquestioned proof of the absence of the typhoid germ, and that its presence in the filtered water is more or less suspicious, because typhoid may at times accompany it. The typhoid germ is never found in river waters unaccompanied by B. coli, although the reverse is, of course, far from true. Just how much these investigations will show we cannot state at the present time, but that they will be of considerable value I have no doubt.

Up to October 1, 1898, of 117 samples of the filtered city water collected at the city filter and examined for B. coli, nine, or 8 per cent., showed its presence in a single colony; five of these samples, however, in which it was found were taken at the times of scraping the filter, or other disturbances of the sand. Of 119 samples collected during the same period from a tap at the City Hall after the water had passed through the reservoir and about one mile of service pipe, four showed the presence of B. coli. The bacterial efficiency of the filter during this period calculated upon the total number of bacteria removed was 99.67 per cent. This taken into consideration together with the B. coli results and the small number of cases of typhoid fever in the city during the year up to that

time, indicates, at least, that the appearance of this germ in filtered water and in single colonies is without any great significance, and it is doubtful if any of the cases of typhoid fever occurring in the city up to December 1st were due to the filtered water supply.

During the course of some work at the filter in October, November and December, some of the beds of sand were considerably disturbed, and owing to the sudden advent of winter weather were not in as good a condition as intended or expected when water was turned on after the last disturbance. Following this a number of cases of typhoid fever developed in the city. It is quite remarkable, however, that even following this period of disturbance the average bacterial efficiency of the filter did not fall below 97 per cent., but B. coli appeared frequently and persistently in the filtered water.

In regard to B. coli in river water, I noticed that in Mr. Fuller's report upon the purification of water in Louisville, he states that in 1897, 21 tests for this germ were made with samples of the water of the Ohio river, and in only three instances was it found. The difference between the Ohio and Merrimac River waters in this respect, and the much greater pollution of the Merrimac River water, can be easily seen, when I state that samples were taken from the Merrimac river on 288 days during 1898, and in 287 of these samples the germ was found. The average number present being about 50 per c. c.

I have stated that it is questionable whether we can place so much confidence in simple bacterial efficiency or percentage removal as we previously have done, for during 1898 tests made with our two largest and best experimental filters showed that while operated at rates of 4,000,000 gallons per acre daily, nearly as good bacterial efficiency was obtained as when operated at rates of 2,500,000 gallons daily, not enough difference being shown to mean much of anything to the average engineer, still the results upon the removal of B. coli were very much better at the lower than at the higher rate. Details in regard to our work along this line will be given in the Report of the Board for 1898.

I have been very much interested in the work at Louisville and Pittsburg, especially have I noticed the remarkable figures in regard to the amount of silt in the Ohio River water at all times, and

especially at times of flood and the consequent apparent impossibility of operating sand filters at Louisville.

But this turbidity is something foreign to New England rivers, except at infrequent intervals, and hence is something we do not have to grapple with.

A rather interesting experiment showing that it is largely silt and not organic matter that clogs water filters has been made at Lawrence during the past year, where we have had two filters in operation receiving water containing much more organic matter than the river water applied to the other filters, but practically no silt. This water has passed through these two filters during the entire year at rates somewhat greater than 2,000,000 gallons per acre daily, and caused no clogging of the surfaces of the filters except that which a slight raking two or three times during the year has removed.

PROCEEDINGS.

ADJOURNED MEETING.

Parker House,

Boston, February 8th, 1899.

President Forbes in the chair.

The following members and guests were present:—

Active Members.

George I. Bailey, Charles H. Baldwin, Lewis M. Bancroft, R. S. Bartlett, George E. Batchelder, Joseph E. Beals, James F. Bigelow, Fred A. Brooks, George Bowers, Dexter Brackett, E. C. Brooks, George F. Chace, Charles E. Chandler, John C. Chase, William F. Codd, Freeman C. Coffin, H. W. Conant, J. W. Crawford, A. O. Doane John W. Ellis, Frank L. Fales, B. R. Felton, Desmond FitzGerald, Z. R. Forbes, John N. Ferguson, Frank L. Fuller, George W. Fuller, Harry F. Gibbs, Albert S. Glover, X. H. Goodnough, Frederick W. Gow, E. A. W. Hammett, John C. Haskell, William T. Haines, T. G. Hazard, Jr., Allen Hazen, Clemens Herschel, Horace G. Holden, Frederick S. Hollis, William Jackson, H. R. Johnson, Willard Kent, Patrick Kieran, Geo. A. Kimball, Horace Kingman, James W. Locke, Charles F. Murphy, H. A. Nash, Jr., Thomas Naylor, Frank L. Pierce, George S. Rice, Walter H. Richards, George J. Ries, W. W. Robertson, William T. Sedgwick, Charles W. Sherman, Herbert E. Smith, Sidney Smith, H. T. Sparks, George A. Stacy, Lucian A. Taylor, Robert J. Thomas, William H. Thomas, H. L. Thomas, D. N. Tower, William W. Wade, Charles K. Walker, John Venner, Robert S. Weston, William Wheeler, John C. Whitney, George E. Winslow.

Honorary Members.

"Engineering News," by M. N. Baker.

"Fire and Water," by F. W. Shepperd.

Associate Members.

Blake, The George F. Mfg. Co., by George J. Foran.

Hersey Mfg. Co., by Albert S. Glover and A. A. Blossom.

Jenks, Henry F., Pawtucket, R. I.

Lead Lined Iron Pipe Co., by T. C. Dwyer.

Ludlow Valve Mfg. Co., by W. H. Doyle.

Mueller, H. Mfg. Co., by M. G. Milliken.

Mitchell Coal and Coke Co., by J. M. Holmes and G. H. Blake.
Neptune Meter Co., by H. H. Kinsey.
New York Filter Co., by Charles Wilson.
Perrin, Seamans & Co., by Mr. Seamans.
Builders' Iron Foundry, Providence, R. I., by T. C. Clifford.
Smith, A. P. Mfg. Co., by William H. Van Winkle.
Worthington, H. R., by J. N. Chester.

GUESTS.

Alexis H. French, Mr. Copeland, J. A. Stubbs, St. Albans, Vt.; G. E. Hofmaster, Mt. Vernon, N. Y.; F. L. Weaver, Lowell, Mass.; W. F. Sullivan, Lowell, Mass.; G. A. Johnson, Cincinnati, O.; J. B. Wood. Marlboro, Mass.; H. T. McClaren, Arthur Deane.

Fred Brooks, of Boston, was elected a resident active member, and Fred G. Judkin of Franklin Falls, N. H., was elected a non-resident active member, and the Mitchell Coal and Coke Co., of Boston, was elected an associate member.

Mr. George W. Fuller, C. E., chief chemist and bacteriologist, water works, Cincinnati, Ohio, addressed the Association upon the subject, "Relative Applicability of Sand and Mechanical Filters." The subject was discussed by Messrs. Hazen, FitzGerald, Bailey and Sedgwick.

On motion of Mr. Kent, the thanks of the Association were extended to Mr. Bailey for his cordial invitation to the members of the Association to visit the water works of the city of Albany, of which he is superintendent.

Adjourned to the second Wednesday in March, 1899.

QUARTERLY MEETING.

PARKER HOUSE,

Boston, March 8th, 1899.

President Forbes presiding.

The following members and guests were present.

ACTIVE MEMBERS.

Charles H. Baldwin, Joseph E. Beals, James F. Bigelow, George Bowers, Dexter Brackett, E. C. Brooks, George A. P. Buckman, George F. Chase, Harry W. Clark, Freeman C. Coffin, H. W. Conant, Byron I. Cook, A. O. Doane, John W. Ellis, A. A. Forbes, Frank Baldwin French, Frank L. Fuller,

L. L. Gerry, Julius C. Gilbert, T. C. Gleason, Albert S. Glover, X. H. Goodnough, Richard A. Hale, John C. Haskell, L. M. Hastings, V. C. Hastings, Horace G. Holden, Frederick S. Hollis, Daniel D. Jackson, William Jackson, William S. Johnson, Willard Kent, James W. Locke, Theodore McKenzie, Frank E. Merrill, Thomas Naylor, Frank L. Northrop, Horatio N. Parker, Walter H. Richards, T. F. Richardson, George J. Ries, W. W. Robertson, Henry W. Rogers, William T. Sedgwick, George A. Stacy, Frederick P. Stearns, Robert J. Thomas, D. N. Tower, William W. Wade, Charles K. Walker, John C. Whitney, E. T. Wiswall.

ASSOCIATE MEMBERS.

Chapman Valve Mfg. Co., by E. L. Ross.
Coffin Valve Co., by E. J. Chadbourne.
Crosby Steam Gage and Valve Co., by Robert Pirie.
Henry F. Jenks, Pawtucket, R. I.
Ludlow Valve Mfg. Co., by H. F. Gould.
Mueller, H. Mfg. Co., by M. G. Millikin.
Mitchell Coal and Coke Co., Boston, Mass.
Neptune Meter Co., by H. H. Kinsey.
Perrin, Seamans & Co., by H. L. Bond.
Rensselaer Mfg. Co., by F. S. Bates.
Builders' Iron Foundry, Providence, R. I., by R. A. Robertson.
Smith, B. F. & Bros., by Joseph W. Martin.
Union Water Meter Co., by F. L. Northrop.
Wood R. D. & Co., by Mr. Newhall.

The following were elected resident active members :—

Arthur W. Dean, City Engineer, Nashua, N. H.; James W. Blackmer, superintendent, Beverly, Mass.; George Cassell, Superintendent, Chelsea, Mass.; Frederick S. Clarke, Chairman Water Board, North Billerica, Mass.; Joseph H. Linsley, director State Biological Laboratory, Burlington, Vt.

Mr. Kent moved the appointment by the President of a committee of five to nominate a list of officers of the Association for the ensuing year. Adopted.

MR. STACEY. I think the appointment of that committee is an important matter, and I would like to know if there isn't some way by which it can be provided that this committee, which is to be appointed, shall meet at some time previous to fifteen minutes before the nominations are made. That seems to have been the practice within the last two or three years, and I should like to have a limit of time fixed within which the list of officers nominated should be made out previous to the meeting at which they are to be voted on.

THE PRESIDENT. It would be my intention to appoint the committee at once, or within a week's time, and to notify them, of course,

and then they can have a meeting as soon as they can get together, or at any rate in June, when the Association is supposed to meet for one day. At that time, if the committee see fit, they can make the nominations, and their report can be made on the first day of our annual convention, if necessary. That would naturally be left with them, but the idea is to give them ample time in which to consider the nominations, and also to give the members of the Association ample time to examine the list.

MR. STACEY. That is my idea exactly; but you know, and all of the members know, what I have reference to. The committee has sometimes been appointed early enough, but when the time came to make the nominations some of the committee have not been present previous to the hour at which the nominations were to be made, and some of them not even at that time; and that is a matter I should like to see remedied, so that there will be plenty of opportunity to give full consideration to the subject. I think it is of enough importance so that the committee ought to meet and consider it and make the nominations at some time previous to the meeting at which they are going to be voted upon, and that is the reason why I have made this suggestion. I have no doubt the committee will be appointed all right, but I should like to have some provision made by which they should have a meeting and make these nominations a week or two weeks or a month previous to the meeting at which they are to be acted upon.

THE PRESIDENT. Would it not be wise, Mr. Stacey, to make a motion that this committee report at the annual meeting in June?

MR. STACEY. I will move that the committee on nomination of officers for the ensuing year report at the annual meeting in June.

MR. BRACKETT. I would suggest this as an amendment, that the list of nominees be printed in the notice for the annual meeting.

THE PRESIDENT. Will you accept Mr. Brackett's amendment, that the list be published in the call for the annual meeting and be distributed with it?

MR. STACEY. Yes, I will accept that. I understand that we shall vote for officers at Syracuse, and not at our real annual meeting in June, and if the committee reports at the June meeting, then we shall have ample time between that and September to know who the nominees are.

Mr. Brackett. If they simply report at the meeting in June, there would not be any notice given to all the members, unless it was published in some way. My idea is that it should be published in connection with the notice for the meeting at Syracuse, when I suppose the officers will be elected.

Mr. Stacey. I accept that amendment.

Mr. Stacey's motion, as amended by Mr. Brackett, was adopted.

The first paper of the afternoon was read by Prof. W. T. Sedgwick, Professor of Biology at the Massachusetts Institute of Technology, his subject being, "Organisms which Cause Unpleasant Tastes and Odors in Water Supplies." The paper was discussed by Dr. Hollis.

X. H. Goodnough, chief Engineer of the Massachusetts State Board of Health, then read a paper entitled, "Some of the Results of the Systematic Examination of the Water of the Public Water Supplies." The paper was discussed by Prof. Sedgwick, Mr. Parker and Mr. Haskell.

The next paper was one prepared by George C. Whipple, Biologist and Director of Mt. Prospect Laboratory, Brooklyn, N. Y., and D. D. Jackson, Chemist, Department of Water Supply, Brooklyn, N. Y., and was read by Mr. Jackson. The subject was, "Asterionella; its Biography, its Chemistry, and its Effect on Water Supplies." This paper was also discussed by Prof. Sedgwick.

Dr. Hollis read the last paper of the afternoon, which was entitled, "A Brief Account of an Occurrence of Chlamydomonas Alboviridis." The paper was prepared by Dr. Frederick S. Hollis, Biologist, Metropolitan Water Board of Massachusetts, and H. N. Parker, Assistant Biologist, Metropolitan Water Board.

Music was furnished at the meeting under the direction of Mr. F. L. Pratt, of Cambridge.

Adjourned.

JUNE OUTING, 1899.

The June meeting and the summer outing day of the Association was on Wednesday, June 14. Assembling near the North Union Station at about 10 o'clock a. m., electric street cars were taken for Everett to visit the extensive works of the New England Gas and Coke Company. Arriving at the works, the visitors were very

courteously received and shown over and through the various devices, plans and processes of the plant. The day was a hot one, one of the hottest of the season. As gas was the principal subject under our consideration, it might not be exactly complimentary to the young engineer who served us as guide to say that he was filled with his subject; but, as with rivulets of perspiration running down his face he answered a running fire of questions from his visitors, he seemed, at least, to be warmed up to it, and to be possessed of a well-invested stock of information on the subject. On that day the water men were not making light of it.

Through the courtesy of Mr. Whitney, the grand master of the enterprise, we are able to present the brief description of the Everett works which follows this sketch.

Escaping from the heat of gas retorts, the party was taken by the electric street cars to Reading, where a lunch had been spread in the town hall.

Lunch having been disposed of, barges were taken for a ride of some three miles to the filter plant of the Reading Water Works. This was described in a former number of our Journal by Mr. Bancroft, their superintendent.

Arriving at the railroad station, President Forbes called the members to order, and a number of new members were elected, and the meeting adjourned to Wednesday, September 13, at Syracuse, N. Y.

EVERETT WORKS OF THE NEW ENGLAND GAS AND COKE CO.

The works are located in the cities of Everett and Chelsea, and are bounded as follows:—On the south by the Mystic river; east, by the Island End river and Naval Hospital grounds; north, by the Boston and Albany railroad; west, by part of the residential section of Everett. The area amounts to three hundred (300) acres.

The plant consists of 400 Otto Hoffmann ovens, with a total daily capacity of about 2,000 gross tons of coal. It is well equipped with modern mechanical appliances for the cheap handling of coal and coke, and a complete system of condensation and purification for tar, gas and ammonia. The yearly consumption of coal by this plant will aggregate about 800,000 tons.

The coking process will give yearly in by-products, in round numbers, the following:—

627,000 tons of coke.
24,000,000 lbs. of sulphate of ammonia.
8,000,000 gals. of tar.
6,000,000,000 cubic feet of gas.

Three billions of the gas manufactured will be utilized at the works for the heating of the by-product ovens.

In the coking process, which lasts about 24 hours, the gases that first come off from the coal are much richer, averaging some 15 to 16 C. P., while the latter part of the process, the C. P. runs as low as 6 or 7.

The coal used is of poor quality of bituminous coal, and is what is known among bituminous coal dealers as "culm," or "slack."

This coal is discharged at the company's wharf, which has a discharging capacity of some 600 tons an hour, and is dumped into an elevated coal pocket, which has a capacity of 6,000 tons of coal; it is then dumped from the pocket into self-dumping coal cars, of about two and one-half ($2\frac{1}{2}$) tons capacity. These cars are operated by an endless cable, and the coal is carried up by inclined planes to four smaller coal pockets, of about 2,000 tons capacity; the coal cars return empty to the wharf to be refilled from wharf pockets. The coal is dumped into traveling larries, which are operated by electricity, and have a capacity of 6 tons each—the capacity of each oven. The coal is then dumped from the larries into the ovens, while they are at a white heat; the oven is then sealed, and nothing is allowed to escape except through the proper channels.

The coking process, as above stated, lasts about 24 hours. During this time from each ton of coal is obtained:—

10,000 cubic feet of gas.
21.96 gallons of crude ammoniacal liquor.
7.6 gallons of tar.

The first 5,000 feet of gas is taken off and sent to the condensing house, where it is thoroughly scrubbed and washed by the process familiar to all gas men. In this process the tar and ammonia is removed, and the gas is driven, by means of exhausters, into the purifying house, where all poisonous materials, such as sulphur

and CA_2, are removed, and from that point goes into the 5,000,000 cubit feet holder (which is as large as any in the country), and is ready for delivery to the various companies, who will enrich it from 13 to 14 C.P. to 18 C.P.—the candle-power required by law.

The second 5,000 feet of gas is also sent to the condensing house for the purpose of saving the tar and ammonia, and from the condensing house sent into a small holder, and from that point supplied, as needed, to what are known as regenerators, which is a system of fire-brick passages where the gas and air is mixed and a terrific heat is generated. By this means the ovens are heated.

The tar and ammoniacal liquor caught in the condensing house are run into enormous tanks, and from these points the tar, which is the heavier, is pumped into storage tanks, and from that point passed into barrels or pumped to the distilling works, which are to be erected by the National Coal Tar Company, at Everett, where the tar will be distilled, the main product manufactured being pitch.

It might be well at this point to state that most of the tar and ammoniacal liquor runs into these tanks by gravity from conduit pipes over the ovens, where they condense from the gas in its passage through the pipes.

In addition to this a distilling process will be carried on, and aniline dyes and many other articles will be manufactured.

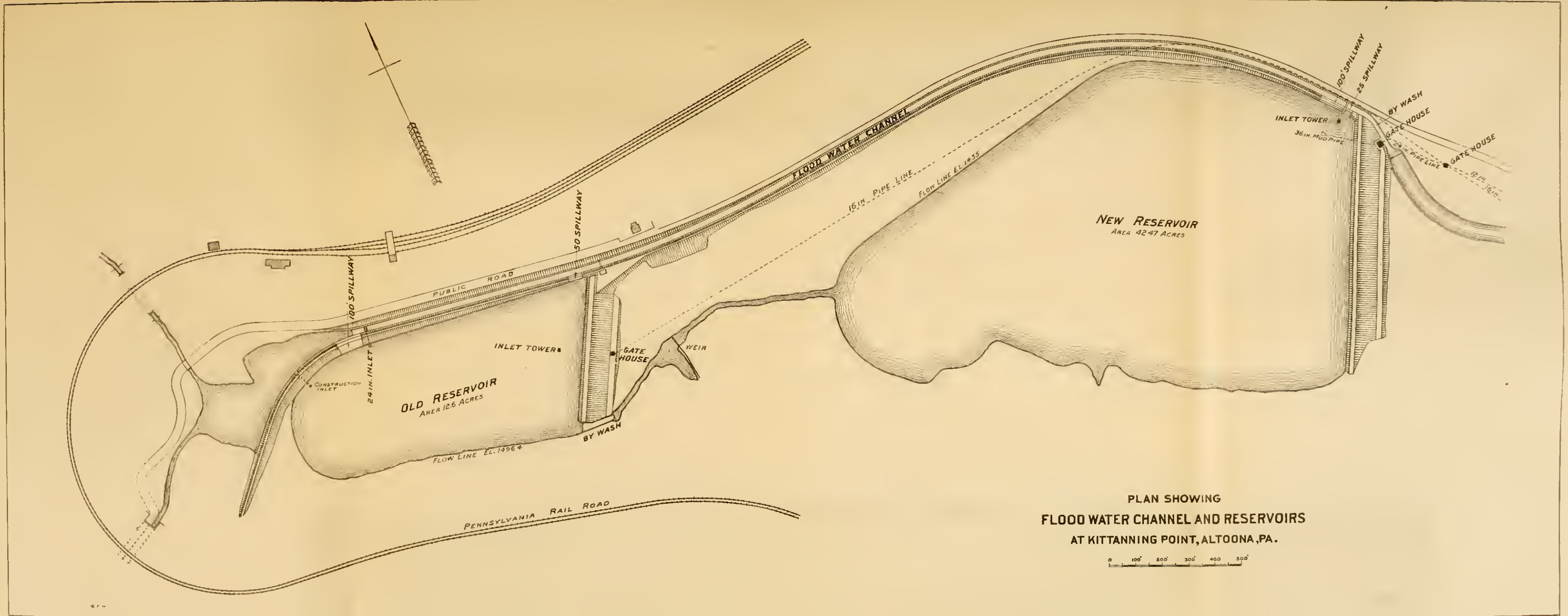
The by-products from the distillation of tar alone comprise some three hundred different articles well known in the commercial and chemical world.

To return to the ammoniacal liquor and tar tank. The liquor is pumped into what is known as the ammonia house; at this point the ammonia is distilled off from the liquor by means of steam, and the ammonia is here thoroughly mixed with sulphuric acid, and ammonia sulphate is produced; the principal market for this article being the manufacture of fertilizers and the finer qualities of ammonia.

The coke, which of course is the main product of the works, after being thoroughly coked, is pushed from the ovens, which are open at both ends, by an electric ram, into what is known as a coke loader—a large iron traveling car. At this point it is thoroughly quenched by water, and when sufficiently cool is dumped from the loader into cars and is ready for shipment.

In addition to the above mentioned buildings and ovens, there is a large power house consisting of eight 250-horse power boilers; two 800-horse power engines, and two 400 K.W. dynamos, which furnish the electric power necessary in operating pushers, larries, loaders and tower hoisters.

The works, when in complete operation, will employ a force of 400 men; this includes a day and night shift.



PLAN SHOWING
FLOOD WATER CHANNEL AND RESERVOIRS
AT KITTANNING POINT, ALTOONA, PA.

NEW ENGLAND WATER WORKS ASSOCIATION.

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SOME NOTES ON THE DESIGN OF WATER WORKS DISTRIBUTION SYSTEMS.

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[*Read September 15, 1899.*]

It is perhaps a little surprising that a more or less thorough search of some ten years' duration through the various works on Hydraulics and Water Supply Engineering has failed to discover in the English language a satisfactory chapter upon the Distribution of Water. As a recent writer upon the subject has said in substance, it seems as if engineers and writers had considered the matter of such small consequence as to be unworthy of special discussion. Because I doubt if any of my hearers have had better success in similar quests than myself, I have determined to take a few moments for outlining briefly some of the essentials of the question.

So far as I have been able to discover, the writers upon this subject have generally assumed that all territory is flat except a convenient hill upon which the hypothetical reservoir is situated. In practice, unfortunately, we do not find things that way. Our cities ordinarily have considerable variations in surface elevation within their limits, and it not infrequently happens that as high a pressure may be required upon the high as upon the low levels. Many times this problem is solved by giving the high level the required pressure and making pipes and plumbing in the low levels strong enough to stand the excess. This is about as sensible a proceeding as it would be to design the plumbing of a house so that fire must be kept in the furnace all summer to furnish hot water for washing dishes. It costs

money to pump water, and the higher the head, the greater the cost. When the territory to be supplied is made up of two distinct levels it is sometimes best to introduce high and low pressure systems. There is, however, usually an intermediate level which unites the high and the low, and does not clearly belong with either, that must be provided for; or it may be that the differences of elevation are too small, or the consumption too low, to warrant a division of the system, and we, in either case, have a problem similar to that involved in the plumbing of a high building without using a tank at its top. Few of us would think of attempting to supply fourth and fifth floors from the same riser that supplies first and second stories, although the water may all be taken at the same pressure at the curb, and certainly none of us would carry a riser to fixtures on the fifth floor and then down to others on the third. So in the larger case of the water works distribution, it should not be attempted to supply high and low levels from the same main if a nearly equal pressure is desired in the two places, nor especially should water be pumped over a summit to low levels and an effort made to supply the summit from the same line. As a corollary to this we may add that water should not be pumped to high ground and then allowed to flow away unrestricted to lower levels. In the latter cases, from the well-known principle of the *hydraulic gradient* it is entirely possible that although the head at the source or the pumps may be considerably above the summit, the consumption below and beyond it may be so great as to entirely destroy the pressure at the high point.

It should furthermore be remembered that the resistances to flow increase pretty nearly as the length of the line, and hence that the most direct route, due consideration being given to grade, should be chosen for the line to supply a given district. In general, the main supplying sloping territory should run near its lower side, as this insures against a summit in the line between the source and the point of consumption. Carrying these principles to the extreme, the distribution system might be compared to a river and its tributary streams with the current reversed. Each tributary and its branches would then be supplying a different level, and there would be no connection between the subsystems. Practically, there are objections to this extreme treatment, and the above principles must be modified to the extent of connecting the subsystems by cross lines, and the individual small mains must also be laced together in order to furnish proper fire protection. The cross lines from sub-

system to subsystem must be arranged with care. If they are to be large, which should be avoided as far as possible, they should be shut off at both ends by gates, to be opened in case of emergency. It is usually better to make these connections by small mains which decrease in size as they depart from the trunk lines, and by which the friction and local consumption tend to prevent an extensive flow from one part to another, except in cases of a large difference of head. In small cities the necessity for cross lines from subsystem to subsystem is greater than in large ones, because in the former the fire requirements stand in a higher ratio to the other demands than they do in the latter. In the large cities each subsystem should be designed to provide for any fire within its limits. In the smaller city this cannot be done, as it would entail excessive expense. So in the former the cross line is needed only in case of a break in the main supplying the adjacent subsystem. These cross lines, if of large capacity, are a never-ending source of trouble where a fine adjustment of pressure is required, for if they are left open such adjustment is impossible, and if they are closed at one point only, they become receptacles for sediment which may under some conditions be decidedly detrimental to health, and will, in any event, be distributed to the consumers whenever the line is opened. Therefore the best treatment is to shut them off entirely, or else arrange them to act as mud drains for the system and blow off their accumulations frequently. Similarly, the cross lines joining parallel mains in which an equal total pressure is maintained must be handled with care, for the only cause inducing a flow through them is the consumption from them ; and this is where, whatever enthusiasts may say to the contrary, there is a proper place for 4-inch, 3-inch, and even 2-inch pipe in a well-designed distribution, for the lines of this class, if only one square long, should be designed to supply nothing more than the consumption to be taken from them. They then become the lowest element of the system, for they have no bearing on that which is beyond ; these lines are made too large more frequently than too small, and it is often difficult to tell which is the greater evil.

The proper gating and draining of a system is a very important matter. Gates should be set at intervals sufficiently frequent to prevent large areas being shut off in case of breaks. About 1,000 to 1,600 feet apart for large mains, 16-inch and above, and 600 feet for small mains, 8-inch and under, is good practice. No shut-off should require the closing of more than eight gates if it can be avoided. It

is often wise to use two tees with a gate between in place of a cross. Large mains may well be gated with gates at least one size smaller than the pipe, a reducer being used at each side of the gate. This is economical in cost and saves time in shutting off, while the additional loss of head will be small. Blow-offs should be provided, if possible, to drain each section between gates on large mains, and large ones of sufficient capacity to create velocities of from 5 to 10 feet per second should be so located as to enable every large main to be easily cleaned out. The most satisfactory arrangement for these is to make the pipe leading to the blow-off gate one or two sizes larger than the gate and several feet long — anywhere from 12 to 50 feet is good — joining the main it is designed to clean by a Y, whose opening is on the same level as the bottom of the main. The Y should be set so that the direction of flow is toward, not away from, its oblique branch. This arrangement insures a large amount of sediment being caught in the connection to the blow-off which is washed out of the system as soon as the gate is opened. It is, in fact, about as satisfactory a scheme for trapping mud as has been devised. In paved streets it will usually pay to enclose the gates in wells sufficiently large to admit a man to make repairs, for, like all other machines, gates get out of order. It is also well to provide manholes affording access to the interior of large mains at frequent intervals.

Pipes should be laid as nearly straight as possible, both vertically and horizontally. Curves where used should be of not more than five diameters radius and preferably of only three or four. Long, so-called easy curves should never be used, as they greatly increase the losses of head. The side openings of branches ought to approximate to the form of the *vena contracta* and the smaller lines should be taken from the top, not the center or bottom, of the larger, as this insures less sediment and foreign matter in the water as it goes to the consumer. This is particularly important where meters are used. When the direction of flow is determinate and uniformly in one direction, Y's are preferable to T's for branch connections. The direction of flow should be maintained constantly in one direction for each section of pipe if possible, and provision should be made for proper circulation in all lines. Dead ends and short dead loops must be avoided if possible, and the larger they are in diameter, the worse the condition if they exist.

The foregoing remarks apply especially to a pumping system or

to one in which the reservoir is situated across a valley from the town. They would not all necessarily apply to the case of a city on the slope of a hill, at the top of which the reservoir is located.

DISCUSSION.

Mr. Kuichling. There is one thing I think Professor Williams should explain, and that is the matter of the resistance of curves. He has made some of the most interesting and beautiful experiments that have ever been made in hydraulics, and the result of them is his apparent heresy as to the resistance of curves. This is a novelty, not to be found anywhere in hydraulic literature. It is confined now exclusively to Professor Williams' mind. I do not think it has appeared in print or even fully in manuscript as yet. I therefore ask Professor Williams to supplement his paper by a brief reference to his apparent heresy.

Professor Williams. There may be some other discussion of this paper, and I should prefer to reply to all the discussion at one time, and therefore I will wait a few moments before complying with the request of Mr. Kuichling.

Mr. Haskell. We have all been in the habit of considering that a straight line would give the least resistance, and the least deviation from a straight line would be, of course, the easiest curve. I don't know but it will be very easy to explain it to our minds in such a way that we will understand that the least deviation would present the greatest resistance. But there is one thing I would like to say in connection with the paper. We have not been in the habit of figuring quite so closely on the sizes of our pipes as the paper would perhaps lead us to do. Our reason for that is principally this: that in designing works we do not consider that the first demand is to be the full capacity of the works. The demand is supposed to increase, and there will be a much greater consumption later on than at the time the works are designed. If we should construct a system as absolutely perfect as possible for the present, the increased consumption in the future would demand the construction of a new system. Also it is a fact that a good many tubercles form in our pipes, no matter how nice the inside coating is. I have known a 4-inch water pipe reduced to an effective diameter of less than two inches; so that it is utterly impossible to bring the original construction of a works down to absolutely the best size for the works at the time. And I

think if we should confine pipe that has got to supply a hydrant to not less than six inches in inside diameter, we would n't make a very bad mistake. In case a pipe is fed in both directions, a 4-inch pipe would probably be ample, if not too much tuberculated. But we can't figure in the construction of a water supply system for a city down to the most economical point for the present time; we have got to allow quite a little margin for the future.

Mr. McKenzie. Mr. President, there is one thing which I noticed, and that is that Mr. Williams recommends that the branches be taken off the mains at the level of the top of the pipe, or, rather, that what we call the blow-off should be reversed, so it will leave at the level of the top of the pipe, to prevent the sediment from getting into the meters. I should like to know whether that is merely a theory, or whether he has observed it in practice, and I should also like to know if castings are made in that way.

Mr. Williams. I will answer that question directly, Mr. President, by saying that is the practice which was introduced by myself, and has been found to give extraordinarily good results in Detroit, and that all of our specials are designed with that in view. They were re-designed after my connection with the works. I really have no right to say that this practice was introduced by me, because my predecessor had introduced it on the larger mains; but I carried it to a greater extent than he did by extending it to the very small sizes. Where we take a 4-inch out of a 6-inch I would have the top of the 4-inch at the same level as the top of the 6-inch.

Mr. Hazen. I don't know the history of it, nor who is responsible for it, or anything about it, but I have seen castings of that description around the streets of New York on a great many occasions for a considerable period, and I know that they are common.

The President. Are there any further questions to be asked of Professor Williams?

Mr. Walker. Mr. Williams says it does n't make any difference if you put an 8-inch gate into a 10-inch pipe. Well, if that is all right, then I have been all wrong all the days of my life. [Laughter.]

Mr. Fish. It is all right, and I say that from the fact we have had it exemplified in the Venturi meter. They will take a Ventur meter and bring down a 30-inch pipe to 12 or 16 inches in diameter, and they say and have proven that it is accurate. They reduce the size of the pipe more than one half, and they say there is no diminu-

tion in the volume of water, and I don't know but we have got to accept it. I don't know whether there is any gentleman here who is acquainted with the operation of the Venturi meter; but you may take a service pipe if you please, for a good illustration of it, and insert a ½-inch corporation cock, as we term it, and run a ¾-inch pipe from that 300 feet, and you may take a ¾-inch service cock and insert that and run the same distance with a ¾-inch pipe, and you can't tell which is which at the end.

Mr. Walker. Will somebody please help me out? [Laughter.]

Mr. Haskell. Mr. President, I have often attempted to help Mr. Walker out on all sorts of questions he has asked me, and I will try to help him out now. And I think the best way to help him out will be to show him how to satisfy himself that this statement is correct, and I think I can do so if he has a special gage attached to any of his pipes. Of course after he has tried the experiment he will let us know whether I did help him out any or not. Now one way that he can determine this question is this: open the gate to a pipe, be sure it is absolutely fully open, look at your gage, and then close the gate and keep closing it until you see that you are losing your pressure.

Mr. Fish. That will be half way.

Mr. Haskell. Will you please let Mr. Walker tell us. It may be a great deal more than half way, depending upon the consumption. If they were only using an amount of water from that pipe which would go through an inch pipe, you could close the gate down until the area was equal to even less than an inch, because the friction at the gate is only for the thickness of the gate, and through the pipe the friction would be for the entire length of it. If you opened the outlet to the pipe and allowed quite a large body of water to go through, you would begin to feel the difference in closing the gate much quicker. So the statement is more nearly correct than people would at first think, that you can put an 8-inch gate into a 10-inch pipe and not affect the amount of water flowing through it very materially, and if Mr. Walker will try this experiment I think he will demonstrate the truth of the statement to his own satisfaction.

Mr. Hazen. Mr. President, some time ago I had the pleasure of looking over the Rochester water works with Mr. Kuichling. He was taking water from Hemlock Lake down to the city through a pipe 38 inches in diameter, and he was filling this pipe and supplying the city through one of his by-pass gates 8 inches in diameter.

The water went through under a high pressure very rapidly, filling the 38-inch pipe and supplying the city of Rochester. I have never been able to understand how Mr. Kuichling convinced the City Council that an 8-inch pipe would n't do all the way down. [Laughter.]

Mr. Kuichling. Mr. President, I did n't convince the Council; I left that out. The contract was too large for me. I presumed it would need a good staff of surgeons to accomplish that result. [Laughter.] So I contented myself with simply making a prescription, and then said to those who did n't understand, "If you don't want to take it you can get another doctor." That was a simple way to manage that.

With regard to the operation of an 8-inch by-pass placed on a 38-inch pipe line, I may say that that pipe line is simply called upon now to do about one fourth or one fifth of its ultimate duty. There is out of a twenty million gallon ultimate consumption at present only about four or five million gallons required, and through the desire on the part of the municipal administration to be economical, devices for measuring the supply or delivery of the conduits have not been furnished, and the water works department has therefore been required to make use of a water gate as a water meter. We therefore calibrate an 8-inch by-pass for convenience of manipulation, instead of a 36-inch valve, as a meter. So many turns correspond to a rate of flow of so many million gallons per day or cubic feet per second, and in that way we keep track of the amount of water furnished.

But the matter of loss of head through gates or meters of any kind is the question at issue here, as raised by Mr. Walker and the preceding speakers. That is all there is to it — a question of loss of head, and how much we can stand. At the Rochester water works 40 feet, 50 feet, or even 60 feet of head may be lost, because only one fifth of the ultimate capacity of the pipe is now required. In the future, when the whole head may be required, there will be nothing to spare, and the main valve will be used to its full opening.

The matter of using valves as meters is comparatively old now. It has been used by others beside myself for a good many years. I have calibrated a 24-inch valve as a meter, I have several 16-inch valves as meters, a 20-inch valve, and several 8-inch valves on by-passes. Mr. J. Waldo Smith, of the Paterson works, has done the same thing with even larger valves. The experiments that he and I

have made on the matter, which are very exact, show that with a pipe of 30 or 36 inches diameter, 24 inches or 16 inches in diameter, when supplying water at full capacity with velocities of from 3 to 4 feet per second, the valve may be closed perhaps one half its travel before any noticeable loss of head is going to take place. The resistance in passing through the valve will be only in a length of the 3 or 4 inches occupied by the valve. Now one such resistance, or loss of head, will perhaps cut no figure whatever at the end of a long line of pipe. On the other hand, when you apply that principle through several hundred valves in a large city distribution system, you will have an aggregate loss of head amounting to so much that it will affect the usefulness of your system very materially, and especially at the time when its ultimate capacity is reached. In the early days of its use the loss may not be felt; but later on, in ten or twenty years, when the pipe is tuberculated, encrusted with various growths, its capacity reduced in some manner or other, then these losses of head begin to be appreciable, and it may not therefore be an expedient thing to do on a large scale. A few instances, however, amount to little. There is more daily fluctuation in the water level of the distributing system of any city I know of than the loss of head from perhaps two or three dozen reductions caused by using smaller valves than the diameter of the pipe; but that practice has got to be stopped after a time. In designing the larger distribution system for our city the number of valves accumulated, owing to the long length of the feed lines, to such an extent that I did not apply the principle of using a smaller valve than the diameter of the pipe. I had no head to spare. I had to serve high ground at a long distance from the reservoir, and I did not think it was advisable to lose 8 or 10 or 15 feet head in the aggregate. That head had a commercial value much greater than the saving in cost on the valves. A few hundred dollars saved in that way would be of no consequence in comparison with the value of serving hundreds of buildings, perhaps, on an additional story. The cost of pumping in those buildings to the additional story is so much greater than the interest on the saving that it becomes of course absurd to talk of it. But in the abstract, as Mr. Fish has put it, the work can be done, as stated by him, through a smaller valve, by tapering the pipe on each side. The illustration of the Venturi meter used by him is perhaps not quite in point, because the general form of the contracted vein of the issuing jet of water requires a very long taper on one side, the

discharge side, and a relatively short taper on the in-flow side. That in practice would be rather costly to introduce in a distributing system. The principle, however, has been availed of often, and by engineers who understood the matter thoroughly and knew what they were about, and it is common practice; and where only a few valves are concerned it is a good practice. But one must be a little careful not to apply the principle loosely, for that will hardly do.

Mr. McKenzie. I would inquire of Mr. Williams if he would really recommend the use of smaller valves than the pipes in the construction of a distributing system with a view to economy in the matter of the cost of construction. Would n't the expense of the reducers on each side of the gate, and of the extra joints which would have to be made, be equal to the difference in cost of the gates?

Mr. Haskell. I would like to ask Mr. Kuichling what the least percentage of error is in measuring water passing through a gate, as determined by his experiments. If we can get it down to one per cent, it is quite an important matter, or if we could even get it down to 2½ per cent it would be quite important.

Mr. Kuichling. In answer to that question, Mr. President, I will say we get it without any percentage of error. We get it exactly, as exactly as it can be measured with any device at any time. Of course, the season of the year makes some difference in the flow of water, but barring that it is simply a question of accurate calibration. Like your pressure gage, it will indicate exactly every time, as long as the conditions remain the same. By noting the difference in pressure, or the number of turns that the gate is open, and measuring the discharge at a number of points, we obtain a curve of discharge, so that when we have, for example, the gate opened 5½ turns, or 5¼ turns, or any fractional part of a turn, if our diagram or table is correct enough, we can read it off as closely as we please. It is wholly a matter of convenience. A large diagram would enable you to read to very small quantities, and for convenience it may be reduced in size. That is all that amounts to.

Of course the calibration of a gate is done with a known discharge, the discharge and the head being measured at the same time; that is, at one experiment. In our city we repeat that once every year in one important gate which is now used for experimental purposes. For example, we want to know the coefficient of friction in a pipe line 38 inches in diameter and 10 miles long. We want to know what that coefficient of friction is with a very small velocity and very

small discharge; in short, a loss of head of only perhaps 4 or 5 inches in the whole length of the line. The gate is then calibrated for that discharge, and we adjust it in the way that I have indicated.

Mr. Haskell. My object in asking that question was really to see if we had found the perfect meter. We have been expecting any day to have somebody come around and introduce to us the perfect meter, one a little better than anything we have yet had. Now we want a meter for one of our force mains. We have a 30-inch pipe which delivers water from our pumping station into our reservoir, and we sometimes wish we knew just what the slip of the pumps was. We have gates situated on that line. We have tried to get the Venturi meter in there, but they want quite a large sum for it, and they don't get down to one per cent in their promises of measuring, and we can get down to within one per cent in another way. Now if there is any way in which we can work our gates in as meters to help us out as a check on the slip of our pumps it will be a great benefit to us, and I think every member of the Association would like to know it. It seems to me to be a pretty important thing.

Mr. Kuichling. I should like to reply to Mr. Haskell's question as to the use of a valve for a meter. It is an exceedingly cumbersome and tedious process to get the physical characteristics, the personal equation as you might term it, of a particular stop-valve. When you have got it, however, and the valve is not spoiled, or the conditions are not spoiled by accumulations of rust or various growths that may take place in it, the characteristics, so to speak, of the particular valve will remain the same. With pumping works and the variations in pressure due to the pump, perhaps things will be a little more difficult to manage than with the constant pressure of a gravity supply. It would be necessary then to know not only the characteristics of the valve for a particular pressure, but for a range of pressures, and the complexity of the operation increases in proportion to the variation to the pressure to be encountered. The coefficient of discharge may not be constant for all ranges of pressure, and that is a thing to be determined in each case by experiments, and these experiments are tedious. It means in our case a week or two weeks' work for a pair of my assistants, who are very rapid mathematicians, and it would probably mean for a man who did not use logarithms a good deal longer time. If he had to do it by the long method it would probably take him a couple of months. That of course makes it impracticable for general use. You use a gate or a

valve as a meter when you can't do anything else, and not from choice.

Mr. Haskell. That answers my question precisely. I thought in the case of a 30-inch pipe, where the expense of a meter would be quite large, that if your computations were not too elaborate we might be able to use them.

Professor Williams. Mr. President, I think I may be permitted to so transgress the rules of some deliberative assemblies as to make a statement at this moment in regard to my personal history, as I have desired for some time an opportunity to pay a compliment to a gentleman for whose ability I have the highest respect; and I wish to say that whatever I have accomplished in the way of experimental work, the bulk of which has not yet been published, but which I hope will be one of these days and not very far hence, is very largely due to the gentleman who was the first to discuss my paper this morning. When I, for the second time, turned my attention to hydraulics, I ran across his paper upon this very question of the loss of head through a 24-inch stop-valve; and I think that, more than anything else that I have come upon in the course of my somewhat brief experience, led me to undertake hydraulic experimentation, and for a considerable period it served as my model and my criterion in the work which I undertook. I think both Mr. Kuichling and myself have possibly improved somewhat on the methods which were set forth in that paper, but it gives me pleasure to testify to the fact that he has been, you might say, not exactly a patron saint, but perhaps a guiding star. [Applause.]

This matter of using various devices for meters is quite an interesting one. Almost any device, almost anything, can be used for a meter, from a brickbat to a straight line of pipe. I not long ago designed a line of 12-inch pipe 1,000 feet long, which was laid on a straight grade, with no specials, probably as handsome a piece of pipe laying as you will find anywhere, to be used as a meter. That was a meter in which there was no restriction of flow over that which would occur in the distributing main itself; in other words, that was the main which was to supply the water to a certain section of territory. We had no pressure to lose, nothing to spare, and we devised that to be used as a meter itself, simply by measuring the resistance in the length of it. To that we could apply the registering apparatus of the Venturi meter, if we choose to do so; but as our pressures were quite low I devised one, which would not be

applicable in cases where there was much draft, and which departs quite materially from the device of the Venturi people.

Then you may also use a bend in your pipe as a meter, and it may be made a very delicate one. You may use a gate, you may use a pair of reducers, you may use almost anything that there is in your distribution system which requires a certain amount of head, or any amount of head, to force the water through. But whatever you use, the accuracy of its measurement will depend upon the accuracy of its calibration. You must calibrate that particular thing in the particular condition in which it is to be used. For instance, if you are going to use your gate in a clean pipe 24 feet long with two right angle bends at each end of it, I should very much question the calibration of that gate for a piece of pipe 12 feet long with two right angle bends at the ends of it. I should further question, if you are coming down to a fractional per cent of error, whether you would get the same flow of water with the same height of gate, that is, the same height of the discs above the seat, if the gate reaches that height by being raised, as would be obtained when the gate was being closed. I should expect if you were closing your gate, when it came to that point the discharge through it would be slightly larger than if you were raising the gate to that point.

These are very fine determinations. They are determinations you cannot begin to think of with a pressure gage; you cannot find them at all; there is no use considering them. If you are accustomed to measuring losses of head with an ordinary pressure gage or even a mercury column, you cannot go to that refinement. A water column may hardly show it; you have got to have something much more delicate than that.

These are matters which are very much like the criticism that I was talking of an ideal system here a little while ago. The refinement is too great for the average consumer. He does n't care anything about it. If you want to use a gate for a meter you can do so, but you must make up your mind there is a good big month's work before you first, and the accuracy of the determinations which are made from that gate will depend wholly upon the accuracy of the work you do in calibrating it, and the closeness with which you reproduce in practice the conditions under which it is calibrated.

The little criticism as to the refinement of design, to which I pointed, is of course quite valid. On the other hand, it is a matter

of experience, which has not changed very greatly in a number of years, that the population in a given area will not exceed a given amount under ordinary conditions. That is to say, take cities that may range from 5,000 to 10,000 inhabitants, for example, and we can tell pretty closely what their population will be twenty years from now, or five or ten years from now, unless there should be some exceptional abnormal condition which might affect their development. For instance, the discovery of coal mines, or the discovery of natural wealth of some other sort, may cause an abnormal increase of population. But in the older and steady-going places it is not difficult to determine pretty nearly what the population will be at the end of a given time. And knowing what the population is likely to be you can also determine pretty nearly what the population per block will be; and knowing the number of lots in a block you can determine pretty nearly how many families you will have to supply. So in designing your system it is possible to design it to meet the requirements very closely.

The statements which have been made with regard to the sizes of pipes required for supplying water for fire protection I think are mainly correct. A 6-inch pipe 300 to 500 feet long will give two very good fire streams; we can count on that. If 4-inch pipe is to be used, I would a great deal rather have one stream than two, and would expect better results. There are places where you would not need a hydrant on the line at all. Take a case where your streets are 300 feet apart, you can put your hydrants at street corners; for the cross line is the place where the small pipe comes in.

Of course we are all well aware that this trouble from tubercles is a serious one. In some places I have seen pipes which have been in service twenty years come out as clean as the day they were laid. If they could coat pipes that way twenty years ago, why can't they do it to-day? I have seen other pipes in the same vicinity, the same water passing through them, which have been in only ten years, and when they were taken out you could hardly tell whether they had ever been coated or not. Now I have no doubt it is possible to devise a coating which will be a protection against any water except from the deposit of sediment perhaps. We will have that sediment under some circumstances, but that can be provided for by blowing out. So when we get to the point of the thing it is simply this: that we can design our works with a great deal more accuracy than has been done heretofore, and in these days, when the matter of

water supply is becoming a more accurate science, it is proper that we should avail ourselves of whatever may tend to increase the accuracy and delicacy of our adjustments.

Of course there are a great many of these refinements that it is not worth while to apply in the smaller systems, because the matter of difference of cost, the matter of cleaning out, and all that is so insignificant. But when you come to a system involving 300 or 500 miles of pipe, the matter of keeping it clean and keeping up your pressures in all parts of it is a pretty serious and important question; and in such cases it does pay to get down to the fine point, and you must get down to it if you wish to conduct the system as it ought to be conducted.

There is one point I barely touched on in regard to this matter of resistance through valves. The loss of head through a valve will depend somewhat on its position in the line. If your valve is at the beginning of the line the noticeable loss of head through it will be somewhat less than if it is at the end of the line. That is owing to the fact that the water when it goes through a valve, or through a contraction, gains a head of velocity, and if you immediately discharge the water you lose that head of velocity; it is simply thrown away. But if you carry the water on through a long line of pipe, that head which was temporarily stored in velocity is given back in pressure, and you have it at the end of your line. So when you close a valve in the end of a line you may close it half way and possibly very materially reduce the discharge; but if it is up at the inlet and you close it half way, you may not be able to find the difference at all when you get down to the other end.

The question has been raised as to the matter of introducing small valves in large lines. I think I restricted myself to saying that in large mains it was more economical sometimes to introduce a valve of a smaller size than the main. We all know the difficulty of closing a large valve, that it takes time and skill. When it comes to closing a 36 or a 42 or a 48 inch valve, we all know that unless we have some hydraulic device to help us out it is a pretty slow process, and a good deal of water may get away if there should happen to be a break in one of the mains at the time.

But of course in designing a plant it is often well to balance the possibilities. It is a question of conditions when you get through. There will be some head lost in going through the small valves, although I am not ready to admit that a slight contraction at the

valve, if properly made by reducers before and after, will produce an additional loss of head over that which would be produced by simply the straight pipe. I am not willing to say it will not, but I think it is an open question which it needs some further experimentation to determine; but I myself should have no hesitation in putting in say a 36-inch valve in a 42-inch main, or a 24-inch valve in a 28-inch main. And I think if you put in a dozen of them in a main two miles long it would be a good while before you would know whether those valves were a size smaller or a size larger. But I would not counsel its being done in small street mains. It is n't worth while to bother with it there, for the cost of the reducers would amount to more than the saving in the valves. But when you come to the large ones, where the valves cost a good deal, then the matter of your two reducers is an insignificant item, and it is economical in cost and economical in operation to use the smaller valve.

I was asked to say something upon my heresy. There are some reasons why I do not wish at this time to go into a full discussion of this subject, so I will only take time to point out to you the data upon which the accepted principles of that branch of hydraulics are based. And it is rather surprising to the investigator to find how many things we actually do not know about hydraulics; how many things we are taking for granted upon the basis of experiments which were wholly out of the range of the cases to which we wish to apply them.

Nearly all the recorded experiments which have been made on the subject of the effect of curvature upon loss of head were made more than fifty years ago. The first that we know of were those of the Abbé Bossut, which were published, way back in the eighteenth century. He experimented on pipes having more or less curvature, that is, having a number of curves. I think there is no experiment on record made by him with a single right angle bend in the pipe. The pipes upon which he experimented had diameters very slightly over one inch, not an inch and a quarter.

The next experimenter was Du Buat, and his experiments covered virtually the same ground, except that he did experiment with some pipes which were about two inches in diameter. He experimented with a series of curves one after another in lines, and in his whole series there were only two experiments where the angle of curvature was less than 120 degrees.

The next experimenter on the subject was Venturi. He made

three experiments, one with a pipe 15 inches long and, if I remember correctly, about an inch in diameter, which was straight. He then put an easy curve in it — I believe the radius is not stated — and measured the loss of head in it, and then put a sharp bend in it and measured the loss of head. He found the bend gave more resistance than the curve did, and that they both gave more resistance than a straight pipe.

The next experimenter was Mr. George Rennie, and his results may be found in the transactions of the Royal Society, for 1831, I think. He experimented on a lead pipe one half inch in diameter. The first experiment, I think, was with one semi-circular bend; and then others with a series of bends in the pipe, and also with a series of right angles. He did not experiment with a single right angle bend. He made a number of experiments, and concluded that the subject of curvature was too complex for him to tackle. He simply said that it did n't seem to him that the formulæ of former experimenters were correct. In this connection it may be proper for me to refer to the work of Dr. Thomas Young who, though I believe he made no experiments upon curves himself, deduced from Du Buat's experiments a formula which fitted those experiments much better than Du Buat's own; and while I do not regard it as an ideal one, it was certainly a very ingenious empiric formula. The interesting thing about Dr. Thomas Young is that he was a physician and not an engineer at all, but he investigated the subject in connection with the study of the flow of blood in the human body. And one who will read his discussion of the movement of fluids through tubes must admit that he certainly possessed a very high comprehension of the laws of the flow of water and of other liquids in small pipes. The article in the "Proceedings of the Royal Society" for 1808 is well worth reading by any who are interested in the older history of hydraulics.

There were some experiments upon curvature that are recorded as described in the "Transactions of the Institution of Civil Engineers of Great Britain," along somewhere about 1850. They were made at Liverpool with lead service pipe one half, three quarters, and one inch in diameter. The radius of the curves is not given and the experiments are incomplete, although they show certain effects due to curvature.

The next experiments, and those which are regarded by the scientific world probably as the most useful, were those made by Weis-

bach, the results of which are presented in his "Mechanics of Engineering." And as it is upon those experiments that the most generally accepted formula is based, I have taken pains to go through them carefully and somewhat critically. I found the bulk of Weisbach's experiments were made upon pipes 1 centimeter in diameter; there were some made upon pipes 3 centimeters in diameter. So far as I was able to find, there was also a record of one experiment, I believe, on a pipe about 1½ inches in diameter. Beyond that diameter I found nothing in his works. The experiments were made upon elbows and curves, the radius of curvature in no case, I think, exceeding 3 diameters of the pipe upon which he experimented. They were made uniformly with short outlet pipes, that is, with a short piece attached to the curve. Many of them consisted of first taking a right angle, then adding another right angle and then another, virtually the old plan of compounding the curvature with the idea that three right angle bends ought to give three times the resistance that one did. I may say they do not by any means.

Then the experimenters upon this subject seem to have lain still until about 1886, when a member of this Association made a series of experiments upon fire streams, and incidentally took up the subject first of the effect of sinuosity upon the discharge of a hose, and afterwards experimented upon the curvature. Mr. John R. Freeman was the first one who came upon the law, which I think we may now accept — at least I am entirely willing to accept it myself — that the loss of head due to a bend does not increase as the radius of curvature decreases, until you get down to a pretty low limit. Mr. Freeman found, in short, that he got more resistance when his hose was bent around a curve of 3-foot radius than he did when it was around one of 2½, and more around a 2½ than he did around a 2-foot radius, and also that the resistance was an appreciable amount. Still, if you will look at the text-books, even those which have been published since those experiments, they will tell you that long, easy curves introduce no appreciable resistance. They will go on and say that no engineer would make curves so sharp as to materially retard the flow of water: and they will say that while Weisbach's experiments were not as complete as they might have been, it may be expected that if you do not make your curves sharper than 5 diameters, or perhaps than 4, there will not be much trouble. I have no hesitation in saying here that you will get better results with curves of less than 4 diameters than with a larger radius, and when you get the larger radius the loss of

head becomes a very serious matter. I might give figures, but they would be from memory and might be inaccurate. So we really are indebted to Mr. Freeman for pointing out to us the true law of curve resistance; and although he at that time did not believe this law was continuous to the limits which I have since found, he nevertheless is entitled to credit for being the first to discover this apparent paradox in the science of hydraulics. I think for the present if any of you are worrying over the sharpness of the curvature in your pipes I may simply say you may sleep peacefully, but you will have to take my word for it just now. I have shown you upon what a small foundation the formula given in the text-books rests, and that Mr. Freeman's experiments on a 2½-inch hose were really far nearer the conditions in practice than the experiments of Weisbach or of any of the rest.

I would refer any who are interested in these old experiments to an article by me in "The Technic" for 1899, published at the University of Michigan. The recorded data and results are there given at considerable length.

Mr. Haskell. I would like to ask Mr. Williams if it is not a fact that Mr. Freeman determined this interesting point in hydraulics by actually weighing the water instead of by a computation.

Professor Williams. I cannot answer that.

Mr. Haskell. Without being at all personal, I may say that I asked the question largely on account of my friend Mr. Walker. I know that Mr. Walker has a good deal more confidence in scales than he has in any intricate computation, and I thought perhaps Mr. Williams might answer the question. I could answer it myself, but Mr. Walker sometimes doubts what I tell him. [Laughter.]

Mr. Smith. The coating of pipe is not under discussion here, but I would like to take exception to what Mr. Williams said about not making as good coating to-day as they did twenty years ago. I don't think it is the coating as much as it is the water. Pipes made at the same foundry are put into different places, and from one place they will be taken up after twenty years and be perfectly clean, and in another place a 6-inch pipe will be reduced to 4. It is just the same way with lead pipes. In some places they will last for forty years, and in other places they will fill up in two. I think it is the difference in the water, and not the difference in the coating.

THE CARE OF FIRE HYDRANTS IN WINTER.

BY GEORGE I. BAILEY, SUPERINTENDENT OF WATER WORKS, ALBANY, N. Y.

[*Read September 15, 1899.*]

One principal reason for inaugurating a municipal water supply is the protection it will give from danger and destruction by fire. The fixture that makes the water supply available for this purpose is the hydrant, therefore an important duty of the manager of a water works is the care and maintenance of hydrants, and keeping them constantly in perfect condition for use.

The problem of how best and most economically to secure this good condition is worth consideration, particularly by the members of this Association, whose membership comes almost entirely from cities lying north of the normal line of snowfall and yearly freezing weather.

While the hydrant was originally placed for use at fires, demands are largely made upon it for other purposes, among which are: for filling street-sprinkling wagons; for flushing streets, sewers, and house drains; for a water supply for street improvement work, such as pavements, new sewers, etc. As all these uses of water are legitimate and can be easily so supplied, their use must be accepted; but as the greater the use, the greater the wear, the care of hydrant maintenance is increased by these conditions. To these uses must be added the occasional abuses by malicious, ignorant, or dishonest persons.

In the city of Albany, which has 800 hydrants, the one in greatest use was manufactured by a local foundry, had no modern improvements, and had this especial defect, that the "waste" was always open, even when the hydrant was in service. A separate frost case giving a space of about five inches all around the standpipe was a feature of this hydrant. The method of attending to hydrants in the winter has been the one found in use by the present superintendent when he took office, and which was continued up to a year ago. It was briefly this: In the fall, the space between the stand-

pipe and frost case was filled with sawdust or manure. The city was divided into districts, each district containing about fifty hydrants. At the commencement of freezing weather, extra help was employed and a man assigned to each district. His duty was to examine each hydrant every morning. If the hydrant was found frozen, he was to throw salt in its standpipe and revisit it in the afternoon, and if still found frozen, to report to the office, when the regular employees would take it in charge and thaw it, or make such repairs as might be necessary. Another duty was to clear away or level the snow for ten feet in every direction, to permit a fire engine to get to the hydrant. Directions were given how to examine the hydrant, which included turning it on for trial if necessary.

While this method was cumbersome and expensive, it was believed to be on the side of safety, for the reason that one defective hydrant might result in damage by fire to an amount largely in excess of that paid by the city for all the hydrant inspection. Several successive years, however, showed no diminution in the number of hydrants reported frozen, although all defective ones were put in complete repair or replaced by modern hydrants.

That we might gain a knowledge of the measures taken in other cities, a circular letter was prepared, stating the conditions in Albany, and asking the methods adopted and results secured, and was sent to the water department officials in a number of other cities. A generous and general reply was received. In many instances, not only were the questions answered, but letters giving details of management were received, evidencing an especial interest in the subject. Included with this paper is a summary of the answers received. The methods used varied greatly, but there were certain details common to all, and from these and our own experience, we have revised our method of inspection and care to a more perfect system, and we believe with a decided economy in cost.

We have all heard of frozen hydrants. We all know that hydrants do not freeze, and that the expression means that the water in the hydrant standpipe is frozen and forms an ice seal, preventing the out-flow of water. Water can reach the standpipe from only two sources, either through the valve at the junction with the street main, or through the "waste." If the standpipe remains empty, the hydrant cannot freeze, therefore good drainage for the hydrant standpipe is a necessity for its operation.

In setting hydrants, where possible, the "waste" of the hydrant

TABLE OF DATA RELATING TO CARE AND INSPECTION OF FIRE HYDRANTS IN FIFTY-EIGHT CITIES IN NEW ENGLAND AND NEW YORK.

PLACE.		Number of Hydrants in Use.	Number Frozen Last Year.	What Department inspects and cares for Hydrants.	Are Wastes connected with Street Drains?	When Inspected, and How.
Amsterdam,	N. Y.	275	2	Water	No	Fall inspection, once a week, and after fires.
Auburn,	N. Y.	400	0	Water	No	In fall and repaired.
Binghamton,	N. Y.	670	0	Water	No	Same as Albany.
Brockton,	Mass.	575	0	Water (except snow)	No	In fall, after fires, doubtful three times a week.
Buffalo,	N. Y.	4,600	0	Water	All	3,800 hydrants covered with boxes and straw, others examined every day.
Cambridge,	Mass.	922	8	Fire	A few	Tested in fall.
Corning,	N. Y.	100	0	Water (except snow)	A few	Fall repairs.
Dunkirk,	N. Y.					In fall, after fires, and weekly.
Elmira,	N. Y.	366	3	Water	A few	Fall and frequently in cold weather — four men in all.
Fall River,	Mass.	912	0	Water	A few	Fall repairs and after fires.
Fitchburg,	Mass.	450	10	Water	No	As demanded. By regular employees.
Geneva,	N. Y.	160	0	Water	No	Fall repairs and after fires.
Hartford,	Conn.	769	0	Water and Fire	Most	Fall repairs and after fires.
Herkimer,	N. Y.	73		Water	No	In cold spells — snow packed.
Holyoke,	Mass.	500	2	Water	No	In cold extremes — snow removed.
Hoosick Falls,	N. Y.	90	0	Water	No	Fall inspection, and when necessary.
Hornellsville,	N. Y.	154	0	Water	No	Fall and after fires.
Hudson,	N. Y.	190	0	Water	A few	Fall repairs, after fires — one man.
Jamestown,	N. Y.	200	1	Water	No	Fall repairs and after fires.
Johnstown,	N. Y.	146	2	Water	A few	Once a week and in cold spells.
Kingston,	N. Y.	352	4	Water	Four	Four or five times a year and after fires.
Lansingburgh,	N. Y.	160	2	Water	No	In fall.
Lawrence,	Mass.	564	0	Water	No	Spring and fall.

Lockport,	N. Y.	400	12	Water	Few	Fall repairs — two men when necessary.
Lowell,	Mass.	1,125	0	Water and Fire	No	Spring and fall repairs — one man from Water Works in severe weather.
Medina,	N. Y.	93	1	Water	No	Fall repairs — one man when necessary and after fires.
Middletown,	N. Y.	231	0	Water and Street	No	Two men.
New Bedford,	Mass.	713	0	Water and Fire	No	Spring and fall repairs, after fires.
Newburgh,	N. Y.	400	6	Water	No	Fall repairs, after fires, in severe cold weather.
New Haven,	Conn.	889	2	Fire	No	Fall repairs, and after fires.
Niagara Falls,	N. Y.	128	0	Water	Some	After fires, and once a month.
North Tonawanda,	N. Y.	320	2	Water	No	One man inspects all.
Ogdensburgh,	N. Y.	150	10	Water	Few	Same as Albany — two men do the work.
Olean,	N. Y.	130	0	Water	No	One man.
Oswego,	N. Y.	324	0	Water and Fire	No	Two or three times in winter and after fires.
Owego,	N. Y.	69	0	Water	No	Fall repairs.
Pawtucket,	R. I.	555	0	Fire	No	
Peekskill,	N. Y.	136	0	Water	No	Fall repairs and after fires.
Port Henry,	N. Y.	50	0	Water	No	Fall repairs.
Port Jervis,	N. Y.	150	6	Village and Water	No	Fall repairs.
Potsdam,	N. Y.	100	3	Water	No	Once a week.
Poughkeepsie,	N. Y.	463	1	Water	No	Fall repairs and after fires.
Providence,	R. I.	1,896	12	Fire and Water	No	Spring and fall repairs — Inspection by Fire Department.
Rochester,	N. Y.	2,750	300	Water	Most	Same as Albany.
Rome,	N. Y.	200	3	Water	No	Spring and fall, in cold weather, and after fires.
Salem,	Mass.	448	0	Water	No	After severe cold.
Saratoga Spa,	N. Y.	250	7	Water	All	Fall repairs and occasionally.
Schenectady,	N. Y.	352	0	Water	Half	Fall repairs and once a week after.
Sing Sing,	N. Y.	115	8	Water	No	Daily.
Somerville,	Mass.	836	11	Water	No	Fall repairs, once a month, and in severe cold.
Springfield,	Mass.	940	0	Water	No	Fall repairs, after fires, and two or three times in winter.
Syracuse,	N. Y.	2,481		Water	Yes	Fall and spring and occasionally.
Taunton,	Mass.	756		Water	No	Fall repairs, doubtful hydrants every day, and after fires.
Troy,	N. Y.	762	43	Water	No	Personal inspection.
Utica,	N. Y.	580	1	Fire	Most	Fall repairs, after fires.
Waterbury,	Conn.	325	0	Water	No	Two men do all work, after fires, and severe weather.
Whitehall,	N. Y.	51	1	Water	Most	
Worcester,	Mass.	1,605	0	Water	Yes	Same as Albany, but not every day.

should be directly connected with the street drain, but in many cases hydrants are placed before street drains are laid, and it becomes necessary to make other provisions for waste water. The common method is to fill in the bottom of the pit dug to receive the hydrant with loose stone or coarse gravel to a point above the "waste" opening. The voids in the stone below the "waste" should be sufficient to take more than the full contents of the hydrant standpipe, thus allowing a complete emptying.

Where the hydrant is set in swampy ground, or in ground saturated with water, or in earth of a porous character which after storms becomes saturated, or in clay soil with no sufficient waste receptacle, the ground water will pass into the hydrant through the "waste." In such cases the "waste" must be plugged and the water pumped out by hand, and the pumping repeated after each use in winter.

Several weeks before cold weather examine and test every hydrant carefully. Repair any defect found. Where minor defects are discovered, which would not warrant extensive repairs, note hydrant as doubtful. See that the valve does not leak, that the "waste" is free, and the standpipe empty. Lubricate the hydrant nozzle cap and the valve rod. After inspection and repairs, mark the nozzle cap with paint, which indicates that it has been inspected and shall not be used for other than fire purposes until spring, when the hydrant is to be reinspected and placed in service for other uses, and the paint mark removed. In winter make the inspection through the regular employees of the department. A raw employee will do more damage than good. Confine the examination to the doubtful hydrants, and those that have been used since the fall inspection, and examine them every day in freezing weather, and until they have been proven in good condition. Do not allow the hydrant to be opened for trial. Use a metal bob to sound for ice. If found frozen, thaw out with steam and pump the standpipe dry, then throw in a handful of salt. If for any reason it is necessary to open the hydrant, let it run so long that all frost will be thawed from the metal, so that no skim of ice will be formed to clog up the "waste." One or two general examinations of all hydrants during the winter is an added safeguard.

Many methods of thawing hydrants have been tried. We find the most effective method is to have a small portable boiler heated by oil, the whole apparatus not weighing over thirty pounds, and which can be placed in a cutter or hauled easily on a hand sled. Attached

to the boiler is a rubber tube the length of a hydrant, terminating in a metal perforated end, to which is also attached a chain for support. The tube is inserted through the hydrant nozzle into the standpipe, the burner lighted, and in twenty minutes the most obstinate hydrant is completely thawed, and the standpipe is then pumped

FIG. 1. — APPARATUS FOR TESTING AND THAWING HYDRANTS.

out. The accompanying view (Fig. 1) shows the plumb bob, boiler, and pump used in connection with frozen hydrants.

There are certain conditions of use which should be determined for the protection of hydrants.

Rules should be adopted preventing hydrants used solely for fire purposes from being operated by any person other than persons in the water or fire departments. Exceptions should be made only on

condition that the hydrant be opened and closed by designated water works employees. When this rule is made it should be strictly enforced, even to the extent of arresting and prosecuting all violators.

Select carefully a modern hydrant for your works. Do not change from that hydrant without the best of reasons, for all its parts are interchangeable, and the cost of repairs is thereby reduced to a minimum; also the regular employees become familiar with it, and no outside help for repairs has to be employed.

When hydrants are to be used for street improvement work, insist that a reducing nozzle with controlling cock for street hose be used. Have this placed on the hydrant in the morning, open the hydrant, and control its flow by the separate cock. At night close the hydrant and remove the reducing nozzle. This prevents wear and damage to the hydrant valve.

Hydrants used to fill street sprinklers should have such a special arrangement for the purpose as you will see on the hydrants in the city of Syracuse. They look better than the special sprinkling standpipe; their cost is only one tenth as much; they give as good results, are more available, and do not interfere with fire purposes. Hydrants so equipped are opened three full turns at the commencement of the street-sprinkling season, and the valve is not shut off until the season ends.

The situation was briefly summed up by the superintendent of water works in one of the Massachusetts cities as follows: —

"In general, if the hydrants are found all right at the fall inspection and are in locations where the drainage is good, and are let alone during the winter, they will be all right, because, as you well know, so long as the water is kept out of the standpipe it is impossible for the hydrant to freeze. The worst thing that can be done to them is to let some man who thinks he knows it all monkey with them during the winter to see whether they are all right, and thus make them all wrong."

DISCUSSION.

Mr. Cook. The hydrant service is very important, and the condition of the hydrants causes a superintendent many sleepless nights. I fully agree with Mr. Bailey that no other department than the water department should have the care of the hydrants. I think it should be insisted upon in all cities throughout the country

that the hydrants should not be used except by employees of the water department.

Mr. Kuichling. That the discussion of this paper may not go by default, I would like to call attention to the importance of the matter and to request at least some remarks of assent or dissent from as many as possible present. It is often said that silence gives consent, and I would like to know whether that is the fact in this case. I want to put myself on record here by saying that I agree in every respect with the recommendations of Mr. Bailey, and I hope that others will have the courage of their convictions either for or against what he has said.

Professor Williams. I would like to endorse what the last speaker has said. I felt that the author of the paper had presented this matter so thoroughly that there was very little more to be said. I can only say that in Detroit, if I may use the term, they went Albany one better. The fire hydrants were handled by the fire department employees, and the water department employees had to let them alone.

President Forbes. I think I can assure Mr. Kuichling that if we had a rising vote in answer to his suggestion it would be unanimous in favor of Mr. Bailey's recommendations.

STANDPIPES.

BY BYRON I. COOK, SUPERINTENDENT, WOONSOCKET, R. I.

[*Read September 15, 1899.*]

After a careful search through the files of the different engineering journals, I have been able to find but little on the subject of standpipes. I have not been able to ascertain where the first pipe in this country was built and to whom belongs the credit of its design, nor have I found any opinion as to its life. With proper care the yearly depreciation is small. Several pipes in various parts of the country have failed or collapsed; as to the cause of their failure authorities differ. The one at East Providence, R. I., that collapsed a number of years ago lies to-day in the same position as when it fell; and in all the testimony of the several trials at law to place the responsibility for its failure, the cause has never been satisfactorily explained. Poor design and workmanship is without a doubt the cause of a large number of failures. Nearly all the pipes that have failed have been of steel, and I know of no case where deterioration has been the cause of a failure. The percentage of failures is too small when compared with the number in use to warrant any very extended investigation where economy demands their use.

The city of Woonsocket, R. I., has three standpipes with a capacity of 1,978,000 gallons. Nos. 1 and 2 are located within 50 feet of each other, No. 3 about 500 feet to the west of Nos. 1 and 2. The pipes are about three fourths of a mile from the center of city and at an elevation of about 250 feet above it.

Pipe No. 1 was erected in 1884 and is of iron, hammer riveted, 50 feet in diameter and 30 feet high. The thickness of shell is as follows: —

Lowest 5 feet, $\frac{7}{16}$ inch.
Next 5 feet, $\frac{3}{8}$ inch.
Next 10 feet, $\frac{5}{16}$ inch.
Upper 10 feet, $\frac{1}{4}$ inch.

The bottom angle iron is $3\frac{1}{2}$ x $3\frac{1}{2}$ x $\frac{3}{8}$ inches, and the top angle iron 3 x 3 x $\frac{5}{16}$ inches. Horizontal seams are single riveted and vertical seams double riveted.

Pipe No. 2 was erected in 1890. It is 50 feet in diameter and 35 feet high, the bottom being 5 feet lower than that of No. 1. This was done to save additional masonry, and as the delivery main deflects quite rapidly from the pipe, the additional 5 feet can be utilized. The bottom plates are $\frac{3}{8}$ inch thick and the thickness of the shell is

Lowest 5 feet, $\frac{1}{2}$ inch.
Next 5 feet, $\frac{7}{16}$ inch.
Next 5 feet, $\frac{3}{8}$ inch.
Upper 20 feet, $\frac{5}{16}$ inch.

The bottom angle iron is 5 x 5 x $\frac{5}{8}$ inches, top angle iron $3\frac{1}{2}$ x $3\frac{1}{2}$ x $\frac{3}{8}$ inches. Horizontal seams are single riveted, vertical seams double riveted; vertical seams have $\frac{7}{8}$-inch rivets, all other rivets are $\frac{3}{4}$ inch. This pipe is of iron, hammered and cup riveted. In this kind of riveting the rivet, after being cupped, is finished with three or four blows of a heavy hammer; this flattens the rivet head and firmly seats the rivet. The foundation of this pipe is on ledge. The bed was composed of lime, cement, and sand, the lime being used to prevent the cement from setting too rapidly, but without success. Owing to the large area to be covered and the small amount of space in which to spread the bed, the cement had commenced to set at the center before the pipe was ready to be lowered.

Pipe No. 3 was erected in 1892, and is 76 feet in diameter and 30 feet high. It is of iron and is cup riveted. The bottom plates are $\frac{3}{8}$ inch thick, and the shell is made up as follows: —

Lowest 5 feet, $\frac{9}{16}$ inch thick.
Next 5 feet, $\frac{1}{2}$ inch thick.
Next 5 feet, $\frac{7}{16}$ inch thick.
Next 10 feet, $\frac{3}{8}$ inch thick.
Upper 5 feet, $\frac{5}{16}$ inch thick.

The bottom angle iron is 5 x 5 x $\frac{5}{8}$ inches, top angle iron $4\frac{1}{2}$ x $4\frac{1}{2}$ x $\frac{1}{2}$ inches. Horizontal seams are single riveted, vertical seams triple riveted, all rivets being $\frac{3}{4}$ inch.

Of the three different kinds of riveting I prefer the hammered cup riveting in pipe No. 2. Fewer loose rivets were found in this pipe and less leakage. This kind of riveting does not leave the

rivet as pleasing to the eye as cup riveting, but for standpipe work I believe it is the best.

The foundation of pipe No. 3 is on ledge, and the bed is composed of sand and coal tar 6 inches in thickness. After the pipe was finished it was found that the bed had been compressed about 2 inches.

The outer portion of the bed was finished with tar concrete pitching at an angle of forty-five degrees from the under edge of the vertical plate. This throws all water away from the pipe and has been most satisfactory.

Every standpipe of large diameter should have a manhole near the outer edge of the bottom for cleaning purposes. A telemeter should be connected with every standpipe, with a recording instrument at pumping station and main office. This instrument is a necessity, as it enables you to compute your consumption at any hour of the twenty-four. You know immediately of an excessive consumption and can locate the trouble quickly. The instrument manufactured by Mr. George E. Winslow, a member of this Association, was installed by the department at Woonsocket at the completion of pipe No. 2; it is simple in construction and does not require the services of an expert electrician to keep it in running order.

With a good foundation, proper design, and good workmanship, the only other important point is to determine what to paint your pipe with, and this is indeed very important. For exterior work I believe the Dixon graphite paint will stand the best. Our pipes have been painted five years with the Dixon paint and are in good condition. For the interior our rule is to paint every two years, and the process is as follows: After water is drawn off the pipe is thoroughly cleaned and then scraped. This is the most expensive part of the maintenance of a standpipe. Your pipe must be clean before applying paint. The simplest and most satisfactory way would be the sand blast; the objection to this is the cost. We use for scraping an old flat file ground to a chisel edge; this, if kept sharp, will do the work nicely. The cost of scraping pipe No. 3 was .092 cents per square yard. For paint I have never had any success with the quick-drying article; the best that I have used is the Durable Metal Coating, manufactured by Edward Smith & Co. For applying the paint I prefer men who are not painters by trade; the novice with a paint brush has not learned the art of covering the most surface with the least paint —

it is just the opposite with him. The cost of applying to the shell two coats and to the bottom one coat was .042 cents per square yard; cost of paint per square yard, .049 cents.

DISCUSSION.

Mr. Haskell. There is one thing in connection with this subject that I would like to hear from gentlemen about, and that is as to the bottom of the standpipe. In order to be sure of good results, the bottom has to be painted at least every two years. Now, it has occurred to me that if a good concrete bottom were put in, the necessity of painting would be obviated, and that it is a practical thing to do. I just throw that out as a suggestion, because I propose to try that with our standpipe, if everybody thinks it is a good thing to do, and possibly I shall if you don't all think so. [Laughter.]

Mr. McKenzie. May I inquire of Mr. Cook what was the process of spreading the cement under the standpipe, and what was the process of lowering the pipe, although possibly he explained that before I came in. I have had difficulty myself in spreading the cement and from having it set before the pipe could be lowered on to it.

Mr. Cook. The No. 3 pipe, which is 76 feet in diameter, was lowered on to a bed of tar and sand, not cement. It was lowered with a common screw jack.

Mr. McKenzie. What pipe was it which was lowered on to a cement bed?

Mr. Cook. The No. 2 and also the No. 1 were lowered on to cement. They are 50 feet in diameter.

Mr. Bassett. In building our standpipes we have had some trouble with the cement running before the pipe was lowered on to the foundation, and we have obviated that by tapping holes in the bottom of the standpipe and pouring the cement in.

Mr. Cook. Making it in the form of a grout?

Mr. Bassett. Yes. We build, of course, a dam about the outer circle of the bottom.

Mr. Cook. So as to get a head for the grout?

Mr. Bassett. Yes, getting a head of about six or eight feet.

Mr. Hawley. I think this matter of getting proper joints under a standpipe is of more importance than is sometimes considered.

I had a case a few years ago where a standpipe 15 feet in diameter and 40 feet high, built of wrought iron in 1888, I believe, suddenly developed a leak one night in January. We emptied the pipe and found that one of the bottom sheets had cracked and broken open immediately over the lap of the adjoining sheet. The crack extended for some four or five feet, and we found that under that sheet there never had been any filling. The contractor claimed that the standpipe was lowered on to a bed of cement and sand, but there was no evidence of anything of the sort. There was nothing but the masonry under the sheet. As a matter of fact, we tapped holes through the bottom and poured in something like two barrels, I believe, of cement to fill the voids beneath. The sheet which cracked evidently had worked over the under lap, and the coating of paint, or whatever had been used, had broken there, and the water had attacked the sheet both from above and below, until it had rusted through immediately over this lap. We repaired it temporarily with a rough patch, and afterwards had the sheet cut out and a large patch put in with bolts. I think this shows the necessity of putting in a joint under the bottom of your standpipe so as to leave no voids, and I think that is well accomplished by making a joint with dry sand and cement mixed, leaving the cement to set after the standpipe has been lowered. In that way there is no setting of the cement, and an even bearing can be secured.

Mr. Martin. In South Framingham we built a standpipe in 1896 40 feet by 80, and we made the bed in the way mentioned by the gentleman who has last spoken, with dry cement and sand, mixed, I think, three to one, and lowered the standpipe on to that. So far we have had no trouble from leakage, and I take it for granted everything is all right.

Mr. Haskell. In preparing the foundation for our standpipe in Lynn, after the foundation was thoroughly hardened we put two inches of dry cement distributed as evenly as possible over the entire structure, and lowered the base on to that; and we found it settled about as nearly level as it is possible to have work settle.

Mr. Beals. Mr. President, we have a standpipe system, the dimensions of our standpipe being 20 feet in diameter and 100 feet high, which seems to be different from any which have yet been mentioned. Our method of setting that — the work being done thirteen or fourteen years ago — was to level what was to be the base just as truly as we could, and then we put a coating of sand and

asphalt over it in the same way that the coating for a concrete sidewalk is prepared. We raked it over as evenly as we could and then lowered the bottom courses, before the standpipe was built, into it. I do not know that we ever had any trouble in the fourteen years on account of its settling unevenly, or for any other cause.

In regard to painting, I will say that we have always painted the outside of our standpipe with the best kind of paint and oil we could get; and as we have n't wanted to see a black or red demon standing in our village, we have avoided those colors, and have painted it very near the color of these walls — as near the color of stone as we could get. The inside of the pipe we have always coated with a preparation of the best quality of asphalt, which has been made for us in the town by a manufacturer of varnishes, asphalts, and japans; and, contrary to the suggestion in the paper, we have employed practical painters to do the work. Perhaps we have made an error there, for possibly they might have put it on a little thicker if they had n't been so professional. We have cleaned it in the same way Mr. Cook has mentioned, except that the best instrument for the purpose that we have found is a piece of saw plate inserted in the end of a board, making a big putty knife, as it were. With that we can easily scrape it out very clean, using steel brushes, perhaps, to brush out what that does not scrape off. And we have recoated the inside, as a rule, once in two or three years with this asphalt coating. Whenever we have emptied the standpipe and cleaned it out we have found that the paint on the bottom has stood better than in any other place, being smooth, glossy, and black after the bottom has been brushed and cleaned. What we have put on has always given good service, and I see no reason from my experience to change our practice.

Mr. Cook. I would like to inquire how long ago the pipe was painted inside.

Mr. Beals. I said our rule was to do it once in two years, I think, and that rule is proven, like all other rules, by the exception. I think it is three years now since it was painted. The last time the pipe was emptied, with the exception of a few patches which would scrape off easily enough, there was no sign of rust. These patches would brush off and leave the iron very smooth, with scarcely a pit in it.

Mr. McKenzie. May I inquire of President Cook whether he has been troubled any with ice in the standpipes, or whether the water is so constantly in motion, rising and falling, that the ice does not bother him?

Mr. Cook. We have had no trouble from ice at all, that is, nothing to cause any leakage. We have had lots of ice in the pipe, but have never had any serious trouble from it.

Mr. Beals. That suggests to me a question I meant to have asked before. With a standpipe of the size and height of ours there is of course considerable fluctuation in the height of the water. Now you spoke of a telemeter being applied, an apparatus devised by Mr. Winslow. I have studied that thing considerably, and I should like to know how you are going to get your results in the winter, especially where there is danger of freezing.

Mr. Cook. I might say that in our case it was far easier to solve the problem than it would be for some. Our telemeter is situated on the No. 2 pipe. Right opposite the ladder I have erected a small cast iron pipe, and that is double boxed. Adjoining that double boxing we have a small building in which we have a stove, and from about the twelfth of December until the first or middle of March we go there once a day and keep up the fire. This place also answers as a storage room for our battery. I think Mr. Bancroft has a telemeter connected with his standpipe in Reading, which is 75 or 100 feet high, and possibly he may tell you how he keeps his float from freezing. I think, however, his is a covered standpipe.

Mr. Bancroft. I have a standpipe which is 100 feet high. We use a telemeter manufactured by the Standard Thermometer Company of Peabody. We use a pressure gage under the standpipe in the pit where the force main goes in, and it gives very fair satisfaction. We have been troubled very much by lightning getting on to our line and burning out the instruments. We have found it almost impossible to get an arrester which would prevent the lightning going across and into the instrument. The line is about three miles in length, giving a good chance for lightning, although the wires are all insulated. We could n't use anything attached to a float at our standpipe. We have an instrument connected with our pump well which works with a float, and that works more satisfactorily than the one with the pressure gage.

Mr. Cook. I would like to ask Mr. Bancroft how close registration that gives you on your pressure gage?

Mr. Bancroft. I think there is a movement for every foot on the recording dial at the station. There is no movement on the recording dial unless there is a foot rise or fall of the water in the standpipe.

Mr. Cook. As showing the value of a telemeter on the standpipe I will cite a case which occurred with us a week ago. My telemeter registers every three inches' rise or fall in the pipes. I think it was a week ago last Thursday it was rising three inches in about twenty-five to twenty-seven minutes. Along about half-past two I happened to be in the office and discovered that the last registration took somewhere between fifty and sixty minutes. I called the engineer up and asked him if his showed the same thing, and he said it did. I watched it the next hour and found it had increased slightly. I knew then that something was wrong, and inside of half or three quarters of an hour we had located a leak on our force main where it leaves the highway some quarter of a mile — quite a serious leak. Without the telemeter I doubt if it could have been located as quickly, because it would have been impossible to have detected it for some time.

Mr. Haskell. Mr. President, at Lynn we use both methods. In our low service reservoir we determine the height of the water by a float, and in our high service one we have the same device that Mr. Bancroft uses. We have a telltale arranged so that when the water gets to a certain height, within a foot of running over, a bell will commence to ring in the pumping station, so if a man is watching carefully he won't run any water over. We have no trouble with our telemeters; both of them work very nicely. The constant registration of the gage has several times denoted to us leaks that we should not have discovered otherwise until some time had elapsed, because they were remote from where any one would be passing, and we should not have discovered them unless our attention had been called by the drawing down in the reservoir; and with the fluctuation that we often get from day to day in our consumption we would have lost a number of million gallons before we should have detected the leak in any other way than by our gage. And it does seem to me as though the telemeters at the present time work with sufficient accuracy for anybody to feel that they are good things to put in. I think they ought to be put in in all cases. They certainly have been of a great deal of value to us.

Mr. Beals. I would like to ask our friend from Reading if he has had any trouble from having his pressure gage underneath the standpipe, and transmitting from there to wherever his recording dial is; if there is any trouble from frost down there, and also if the registration is close, and when they are pumping, how much the surging of the water affects the record?

Mr. Bancroft. We have n't had any trouble from frost, and no trouble from the surge of the water. The surge is comparatively small, and there being no movement except upon a foot of change, it would n't show on the gage. Our standpipe is 30 feet in diameter, and we thought registration every foot would be close enough. It can be made closer than that if it is desired.

METHODS OF ASSESSMENT AND COLLECTION OF WATER RATES.

BY F. H. CRANDALL, BURLINGTON, VT.

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Inasmuch as the object for which municipal water boards in general are striving, the supply to the public of water as nearly "free as air" as is consistent with the cost of delivery, is greatly facilitated by an equitable assessment and impartial enforcement of regulations relative to obtaining remuneration for benefits conferred, this matter of the assessment and collection of rates is of interest.

When the idea that an indirect tax affords the easiest and least felt method of raising funds obtains and the argument that "the water tax comes easy" or that no one complains of the water tax passes current, or when for any other reason the object sought is, instead of low rates, the greatest possible revenue from the water works, that there be equitable assessment and impartial enforcement of regulations is equally desirable.

The first division of this subject to suggest itself is that between the schedule and the meter plan, — between the plan under which it is undertaken to rate the value of benefit received or service rendered by the number and nature of the uses and benefits accorded, regardless of the manner in which they may be used or abused, and that under which it is undertaken to rate the value of benefit received or service rendered, so far as possible, by the amount of the consumption of water.

In view of the fact that the rating by fixtures must, from the nature of the case, be arrived at in total disregard of the principal factor of the cost of their supply, the habit of the consumer, that this plan should afford such generally satisfactory results as it has in the past and now does is quite remarkable. A proposition to settle with one's butcher or grocer on the basis of what Professor "X" estimates to be the amount one ought to eat, plus another amount which the same or some other learned gentleman estimates one is liable to waste, would hardly be regarded as a good business propo-

sition, even in communities where no other method of purchasing water is known.

So long as the supply is abundant and a reasonably satisfactory schedule of rates can be agreed upon, the acquaintance of the water meter need not be cultivated; but when the necessity of such a friend does arise, when the supply abundantly sufficient for legitimate needs proves insufficient to meet also the demand in vogue for waste, or when an equitable schedule rate for various uses cannot be reached, as has been amply demonstrated by general experience presenting numerous object lessons like those furnished at Reading, Richmond, and Atlanta, these brass clerks of the water department will be found capable, efficient, and painstaking servants, more liable to error in favor of than against the consumer.

The principle that risk of any kind has value is universally recognized. In making a low rate for water to consumers who agree to cause no expense by reason of wasteful or careless habits, the water department makes no new departure.

A meter rate, based upon the value of a legitimate consumption, enabling the taker by the exercise of reasonable care and economy, while benefiting the city by the reduction of waste, to secure to himself a corresponding benefit in the reduction of his bill, has in repeated instances resulted in less dissatisfaction over the collection of thousands of meter bills than over the bills recorded by the few dozen meters with which the system was inaugurated.

This condition of affairs is, perhaps, frequently due to the start in the use of meters having been made with rates and regulations under which the greatest mutual benefit was not possible, and to the very gradual acquirement by the general public of the knowledge that with meters, as with figures, apparent misrepresentations do not occur without cause.

That sage remark relative to the inability of figures to lie, together with its corollary, will be found not inapplicable to the case of the automatic machine for measuring water. The greatest benefit which can accrue to the works from the use of meters is freedom from the cost of waste upon metered premises. In proportion as this expense is removed it becomes possible to permit the takers to participate in the benefit. Without the impulse of participation by the takers the greatest benefit to the works appears to be impossible.

The system which permits the economical meter taker to obtain his supply for no less than the schedule rate for such use, and that under

which the works assume not only the expense of the maintenance of the meter system, but also that of leaks on metered premises, are too one-sided to be productive of the best results. The advantage to be derived from the use of meters to be a maximum must be a mutual advantage.

The features rendered conspicuous by the different methods of development of either the schedule or the meter system are numerous and interesting, all having, no doubt, their reasons for existence and their peculiar fitness for the circumstances causing their development. The limited time at our disposal will permit of our taking up of but a few.

The frontage tax, the assessment plan, the sliding meter rate so worded as at various points to offer a premium for waste, and the one so expressed as to cause any increase of consumption to be accompanied by a corresponding increase in cost; the minimum meter rate; the flat meter rate; the charge for the protection afforded by both public and private fire hydrants and pipes; the charge for metered use and waste, both public and private; and the most economical, least productive of friction, and most generally satisfactory method of collecting water rates, are all old and yet eternally recurring questions.

It is a matter of general experience that nothing worth having is without a pecuniary value which must in some way be met, if not by the owner, user, or party benefited, by some one else. The burden thrown upon the shoulders of the ratepayers in general by the failure of an individual or class to return an equivalent for service received, though perhaps when divided among so many an inconsiderable amount for each individual, is like the suit of clothes in the commercial traveler's expense account, there just the same, and with more questionable propriety. It is only when all benefits conferred are assessed upon the benefited at a fair and reasonable rate, with no favored class getting something for nothing, or closely approximating that condition, — of which nature is no more tolerant than of a vacuum, — at the expense of the water department, or in reality at the expense of their less favored fellow citizens, that it is possible to approach the goal, whether it be water as nearly free as is consistent with cost of delivery, or the greatest possible revenue from the water works.

We are all aware that there exist wide differences of opinion in regard to this matter, perhaps not as to the desirability of equitable

assessment of rates and impartial enforcement of regulations, but as to what constitutes equitable assessment and impartial enforcement.

The subject of equitable assessment of water rates, in common with most others, appears different from different points of view, and the diversities of opinion in regard to it may be attributed fully as much to the great variety of conditions under which it is viewed by different people as to the differences of the people themselves.

Self-interest unquestionably exerts no inconsiderable influence on the formation of opinion, and the frequent recurrence and examination of a single phase only of a question has a tendency to warp the judgment and produce one-sided views.

To one employing a large force and using large quantities of water for the philanthropic purpose (most manufacturers are philanthropists) of enabling his employees to earn a living, and incidentally for what there is in it, it naturally seems that the manufacturer should be allowed a particularly low rate. Large amounts accrue to the public treasury from taxes assessed against him and his employees. The local trades people of every class derive a direct and considerable pecuniary benefit from the presence of his plant in the community. The town was made what it is by its manufacturing interests, which cannot be regarded otherwise than as public benefactions entitled at the hands of the town to every possible consideration. It being necessary to maintain water works for other purposes, the furnishing of the additional amount of water required for large consumers necessitates but little, if any, additional expense, and receipts from such sources may be regarded as clear gain.

The cost of 1,000 cubic feet of water pumped, figured from total maintenance, being about $1.00, and figured from pumping station expenses alone about twenty cents, there is an actual profit of about eighty cents per thousand cubic feet on the water sold to large consumers at cost figured from total maintenance.

Inasmuch as the interest, sinking fund, and general management charges are in no wise increased by the furnishing of the additional amount required by unusually large consumers, the large consumers see no reason why they should be asked to pay any part of such expenses.

To the owners of vacant lots the frontage tax or assessment for betterment due to the laying of a water main does not appeal favorably. The party desiring that a water main be laid in the new

street which he is about to open for the purpose of booming the town and increasing its grand list, and incidentally, perhaps, for some other purpose, can see no reason why he should be put to any expense in the matter.

From the point of view of the enthusiastic worker in behalf of some very commendable religious or charitable institution, there is no sense or reason in the public charging for water used by an institution maintained solely for the public good.

The party having a fine lawn to keep up for the public to gaze upon, for which, beside considerable time with a lawn mower, a large quantity of water is requisite, feels that if he is to be charged anything for such use of water it should be but little.

Then there is the party who pays the minimum meter rate, and on finding that he might have used more water for the money, is so impressed by the fact as to forget that he has had all the water he needed, and received at the hands of the water department what he could by no other means secure for the same money, and can see only as he puts it, "that he is being compelled to pay for what he has not had."

And the party, if the sliding meter scale be in vogue, who can see no reason why, inasmuch as the water works belong to the people, and the people in proportion to what they have contribute to the public treasury at the same rate, one taxpayer or stockholder in the water works should be able to get water for any less or be compelled to pay any more than any other taxpayer or stockholder. He does not admit the applicability of the wholesale principle of trade to the case in question and sees equitable assessment only in a flat meter rate. While from his position he can see that the manufacturer made the town, he thinks that he discerns also that the town made the manufacturer, and that it does not require any great sagacity to decide who has made the most. He can see just as much justice in compelling him and the general public to contribute to the expense of maintaining a private lawn, in regard to the maintenance and use of which he has no voice whatever, as he can in requiring that he contribute to the support of a charitable or religious institution in which he takes no interest and in the management of whose affairs he has no voice. In fact, he can see naught but injustice in either, and in the latter a direct contravention of the Constitution of the United States.

In regard to furnishing water to any particular class at a rate

based upon the maintenance of the works by the other takers, it appears to him better that benefactions undertaken at public expense should be made through the appointed channels, so as to be apparent not only to the recipients, but also to the donors, and appreciated by the public at large. He would have the Biblical injunction relative to allowing light to shine obeyed, and not permit its brilliancy and any credit accruing to the town therefrom to be concealed under the bushel of supposedly equitable water rates.

It is contended that individual cleanliness being conducive to the general welfare, means for enabling the same should be furnished free of charge. This is a very pretty theory, and merits a place alongside that, that water should be free as air; but, unfortunately for all theories — and there are many contemplating free water or water at a merely nominal price for certain uses — every quarter furnishes a new demonstration of the fact that the only way to insure reasonable economy in the use of water is by causing it to become a direct pecuniary issue with each individual taker.

There are two ways of accomplishing this, one by means of the measurement and sale of water as other commodities are measured and sold, the other by a system of rigid inspection and penalties impartially imposed, to which latter the average water taker does not take kindly.

Any inspector is well aware of the fact that visions of yards of plastering thrown down and carpets spoiled on account of a leaky fixture and stopped-up drain, of new fixtures rendered necessary on account of long-continued waste, and of large meter bills and fines as the results of a like cause, are his best allies in the never-ceasing strife to keep the consumption within reasonable bounds, and make reasonable economy in the use of water a direct pecuniary issue with the takers.

What inspector has not frequently been told on calling the attention of some most estimable party to the constant flow permitted from a fixture in need of packing, "We pay by the year," or, "I pay too much for water any way, and am not likely to use more than my money's worth." This latter opinion, in towns where from fixtures in public buildings, schools, etc., public servants are allowing water to constantly run to waste, is not unreasonable. If water is not of sufficient value to warrant the prevention of waste in public buildings, the shutting off of public fountains during the night or

during a rainstorm, why should the individual be expected to spend his time, or, worse yet, his money, for the checking of waste?

The evil effect of the toleration of gross carelessness and useless waste of water in public places does not terminate with the waste itself, but is more felt in its encouragement of waste in schedule ratepayers and breeding of dissatisfaction with rates among metered consumers. There is little reason to expect the individual to respect regulations for which the corporation making them by the acts of its officials — and actions speak louder than words — manifests an utter disregard.

To the party who has ignorantly or carelessly permitted a large amount of water to run to waste through a metered service, it is liable to appear that the extra cost of the unusually large amount due to his own negligence or that of his agent over that of an ordinary amount should be borne by some one else than himself. The reasons advanced for permitting the cost of such waste to be borne by the takers in general rather than by the party whose business it was to look after the fixtures on the premises on which it occurred are not numerous, though varied in expression and under certain circumstances quite convincing. That the taker was unfortunate; that he resided out of town; that his tenants were not at all mindful of his interest; that a like leak on the premises of an unmetered taker would have cost the taker nothing; that the leak was not easily located; that it is well to keep on friendly terms with consumers; and that such action, coupled with the warning that it will not be taken a second time, tends to avoid friction at the time, and to prevent a repetition of the cause; are among the number. While perhaps these reasons, in discussion with the negligent party, seem of apparent weight and pertinent to the subject under consideration, at any other time, or in discussion with a party whose degree of wastefulness has not quite reached the proportions deemed worthy of reward, they appear for the most part quite irrelevant.

Policy may sometimes suggest that waste be permitted for purposes of courtesy, to prevent friction, or for some other reason. The legitimacy of such action is, however, bound sooner or later to be called in question, and a rebate made on the ground that a waste of any considerable amount occurred without knowledge or fault of some one, is obviously made without ground. A waste of any considerable amount without the knowledge of the party whose business it is to attend to such matters, or the non-existence of such a party

looks, at the outset, like a grievous fault, which will be none too grievously answered by the payment of the bill.

The party at fault is not apt to criticise the course of reasoning adopted to free him from the natural consequences of his error, and the takers who pay for what they use and waste may, perhaps, be a long time in finding out that the treatment accorded them is not exactly that accorded to some others. When B, C, D, and others do learn that A, because his larger consumption was caused by waste and not by legitimate use, or for some other of the equally good reasons assigned in such cases, has been permitted to receive a rebate, to pay much less than they for a like quantity of water, it is liable to be a difficult matter to convince them that equity or a desire to deal justly had anything to do with the settlement. It may be found that friction, instead of having been avoided, has been transferred, and the heat so intensified as to sweep all explanation and argument before it.

While there is no good reason why the city should be at the expense of making frequent meter inspections for the purpose of preventing waste, there is no means involving so little injustice to those who neither need nor wish assistance in such matters, so well calculated to lessen friction in the collection of meter rates.

Most water works are intended to serve the double purpose of fire protection and water supply, neither of which can be classed as universally the principal cause of the construction of the works. Each may be subdivided into public and private.

The question as to whether private fire services are a sufficient public benefit to warrant the assumption by the public of the expense of maintenance and legitimate supply, beside the risk of their resulting in damage rather than benefit, both to the user and to adjacent property, as well as the risk of their illegitimate use, is not everywhere encountered under such uniform conditions as to warrant its being answered with the uniformity that it is.

The annual cost of public fire protection should be assessed upon those benefited in proportion to the benefit received. To really do this is impossible. By the frontage tax, direct assessment upon real estate, hydrant rental, or direct appropriation from funds raised by general taxation, the end desired is approximated.

The needs of fire protection may frequently and at short notice demand double the regular rate of consumption in all except the

largest cities. To meet them a reserve supply and a capacity for delivery far in excess of ordinary needs are requisite.

The interest on the additional cost of a fire protective works over that of works designed to furnish domestic supply only may be assumed to fairly represent the cost of the protection afforded by the water works. The amount of water used, even at the maximum, constitutes but a small and unimportant part of the total cost.

It is evident that neither the cost of nor the amount paid for fire protection in other places, which latter amount is frequently determined without regard to the former, furnishes information of any value as to what the former is or the latter ought to be in any particular case.

We start out with the idea that the value of the supply of individuals and private corporations for domestic and industrial uses, and the supply of the general public for schools, public buildings, fountains, parks, troughs, street watering and cleaning, flushing sewers, etc., may fairly be based upon the quantity of water consumed, no cubic foot furnished costing more or less than any other cubic foot, but we at once find that a modification is needed. In the first place, the value of the supply is not strictly proportional to the amount of water used, inasmuch as the ability to obtain water under pressure, even in case none or practically none is used, is of value, and in the case of small consumption constitutes so large a proportion of the value of the service as not to be neglectable.

This matter may be equitably adjusted in various ways, none better than by the establishment of a proper minimum rate, which, when applied to meter takers, serves also a good sanitary purpose.

The question also arises as to the propriety of making the prices for water vary, as the prices of many other commodities do, between wholesale and retail customers.

So long as the wholesale purchaser pays for like quantities as those used by the retail purchaser a like price, and the wholesale purchaser receives the favors accorded to that class only in proportion as increased demand shows the wholesale nature of the transaction, there seems to be little ground for complaint of a reasonable recognition of the difference between large and small consumers. The correct solution of this question will vary with the conditions obtaining in different cases; the advantage, however, of so wording the sliding meter scale as not to admit of obtaining an increased quantity of water for a less amount of money is apparent.

The long lists extant of differing schedule prices for delicate variations of use and accompanying waste of water and for different degrees of benefit derived from the presence of water mains attest the general earnest desire to make the assessment of water rates fair and just, and are in themselves monuments of patient and painstaking research necessary to the discovery, not to mention the rating on an assessment roll, of such multifarious uses and benefits.

We might go on indefinitely examining the different aspects of the question of the assessment of rates as viewed from different locations and from amid different surroundings; but from the few mentioned it is apparent that an equitable assessment cannot be arrived at off-hand, that an assessment found pretty generally satisfactory in one case may not prove at all so in another, and that at the best, perfectly equitable and satisfactory assessment can only be approximated.

A public monopoly, having power to refuse to supply water to premises against which bills are outstanding, whose bills are made a lien on the property where they accrue, would seem in view of the means at its command for securing its dues to be in a position to ignore the consideration of methods of collection. The method of assessment having been satisfactorily adjusted, the expenditure of any considerable amount in making collections would seem to be unnecessary.

All water works are not in this position, however, and even in the case of those that are, a very slight knowledge of human nature enables one to perceive that great advantage will accrue from the use of popular methods.

The method of having very rigorous and specific regulations relative to the collection of rates to be used mainly as a bluff, of making the enforcement or non-enforcement of rules a matter of judgment, while perhaps under certain circumstances or for a short time capable of yielding satisfactory results, is not, when generally understood and appreciated, calculated to meet with popular approval.

A light penalty for failure to pay promptly, or a small discount for prompt payment, and the discontinuance of the supply with attendant costs in case of continued delinquency, are generally satisfactory features of most methods of collection.

The reports of numerous cities offering a discount for prompt payment, and granting the discount under no other conditions, that about ninety-five per cent of the ratepayers secure the discount, and

but a fraction of one per cent insist on the discontinuance of the supply; and reports of very much the same tenor from cities impartially enforcing a penalty for failure to pay promptly, leave no room for doubt as to the general satisfaction with such methods.

To one accustomed to the bad debts and items chargeable to profit and loss in private business, it seems remarkable, if not incredible, that such results as are reported can be obtained; that, for instance, of twelve months' bills to the amount of $474,000, at the end of the fiscal year but $68, a very small fraction of one per cent, remains unpaid. By investigation, however, one may learn that the above-cited case is not unique. Like results are wont to obtain where regulations are enforced with like impartiality.

That people are not alike and cannot be treated alike, that circumstances alter cases, and that discretion should be used in everything, no one has a better chance to learn than the water registrar, who is also in a position to appreciate the facts that it is only occasionally, not always, that circumstances alter cases, that the most well-meaning and capable of executive officers is liable, at times, to be unduly influenced by the manner of the presentation of a case, and that a most effective way to minimize such errors and insure uniformity of action in accordance with the ideas of the majority is by the enactment of such regulations, plainly and unequivocally expressed, as it is desired to enforce, and the limitation of the exercise of judgment to matters not covered by regulations.

The characteristic of any method of assessment and collection of water rates receiving the most general approbation in the long run is an impartiality in the performance of duty that, recognizing neither position nor influence, serves every one alike.

DISCUSSION.

Mr. Walker. We have our meter rate in Manchester, and we read the meter and we get pay for what goes through it. If a man's meter bill is $17 or $117, he has got to pay it just the same. We go by the meter, and I don't know any other way to do, if you have a meter, than to go by it. [Laughter.]

Mr. Kuichling. I would like to inquire of Mr. Walker what he does when the meter goes against him. Does he always go by the meter, whether it is right or wrong?

Mr. Walker. Well, when it goes against us in Manchester we take the "next preceding" and reckon by that.

Mr. Kuichling. I was induced to ask that question because of a little case which came up with us where the meter bill of a railroad dropped off some $600 a month.

Mr. Walker. That is quite a drop.

Mr. Kuichling. Yes, a good deal of a drop. The question was, who was to blame, the meter, or the railroad, or somebody else? We found it was the meter which was to blame. It took it into its organization to stop registering, and a month went by before it was discovered. The tactics suggested by Mr. Walker were adopted in dealing with the company, but I have n't heard the result. The company naturally made a protest and said it was a poor rule which did n't work both ways, and how the municipal authorities ever settled the matter I don't quite know. But the ethics of the question are now fairly before us; in a case of the failure of a meter to register properly, what is the right thing to do? I should say in such a case as that you should test your meter thoroughly, and then try to reach some kind of a result on the basis of the preceding period of use when the meter was not under suspicion. I believe that to be the right thing to do; and conversely, if the meter over-registers you should make a reduction to correspond. I know of only one such case where a meter over-registered largely, and that has been a mystery to the manufacturer of the meter and to myself ever since. It slipped the cogs somehow and began to over-register. The consumer demanded a rebate, and he also thought it was a poor rule which did n't work both ways.

Mr. Sullivan. I was about to ask the same question as the preceding speaker, as to what to do in such cases. In our city, when we have a meter reported as being out of condition, we test it and then put it back, or place one of the same size and get a reading for a month, and then if the meter runs regularly for a month we average the consumption for the last six months and send a bill to the consumer for the amount of water that we suppose he uses. But the other day we had a very peculiar case. A man came into our office and said he thought he was paying for more water than he was using. He brought me in the report of the amount he had paid each month for the last six years. We found on examination and comparison of the books that the amount he paid was very regular, I think it averaged about $50 per month; but for the year 1899

he had paid from January 1 to September 1, in those eight months, about twice as much as he had paid in any one year of the previous six or seven. We made an examination of the meter and found that he had not been paying for water enough in the preceding years, and that for the last six or eight months he was simply paying for the amount of water he was using. We got a report from our inspector last December that he thought the meter was out of order, and we then had it examined and we placed a new meter in operation there. We found that one of the cogs in the old meter was caught and that it did not register properly, and the fact was that it had been working in favor of the consumer, so that for the last six or eight years he had not paid within fifty per cent of what he ought to have paid.

Mr. McKenzie. The paper discusses in a very lengthy way a great many problems with reference to meter rates and the use of meters, but I don't see that we get a great deal of advice or information out of it as to rates and methods. There was one point I wanted to inquire about, and although the gentleman who read the paper has been obliged to leave, I presume there are those here who are familiar with the practice in regard to the collection of meter rates in connection with fire hydrant rental and automatic sprinklers for fire protection. I have noticed on the cards giving the meter rates through New York that in many cases, where we have ordinarily been collecting $15 or $20 a year for each fire hydrant and perhaps $10 or $15 a year for each 100 sprinkler heads, where you make a meter rate you specify so much for 1,000 gallons or so much for 1,000 cubic feet. In some cases where but little water is used and the water is taken largely for fire protection, the supply for ordinary manufacturing purposes being pumped from the stream, you actually reduce your income very considerably by charging a meter rate; and I would like to ascertain what has been the practice in the matter of charging for fire hydrants and for automatic sprinklers where a meter is inserted and water is paid for by meter rates.

Mr. Walker. Can any one answer the gentleman's question?

Mr. Sullivan. I will state that in our city we do not charge anything for water used for automatic sprinklers. But I will say in this connection that it is our experience in furnishing large manufacturers, of whom we have a great number in our city, that they often tap the main pipe which goes into the mill for fire purposes and use it in cases of emergency; and we are intending to oblige

every manufacturer who has water service for fire purposes — and the insurance companies of our State require them to have a separate service for fire protection — to put in a meter on the fire service so that we can find out whether or not they are using any water that they are not paying for. But, as I say, they are supposed to get fire service water and their automatic sprinkler service water free.

Mr. Hawley. In our town we make no charge for water for fire protection where a party lays his own pipe. I was particularly interested in Mr. Crandall's paper, and I had hoped we might be given some information in regard to the assessment of minimum rates, and how they can be collected, whether they can be collected in advance or not. I understand the courts in some of the Western States have made some peculiar decisions in regard to some of these matters, and we have recently made a change in the collection of our rates. When the city bought the plant in 1895, a fine of ten per cent was added to the bills not paid within a certain time. Unfortunately the next year we caught the city solicitor for a pretty good sum, and he immediately decided that the addition of the ten per cent was unconstitutional, and the ordinance was then changed so that all we could do in the case of a delinquent was to shut the water off. Human nature is a good deal the same the world over, and you can only make some men, who won't pay their bills promptly, pay at all in one of two ways: either make them feel it is for their benefit to pay it voluntarily, or else take a club and force them to, and the latter method oftentimes causes a good deal of friction and trouble.

During the past year, under the advice of another city solicitor, a new one, we have reëstablished the fine, with the result that we have collected a much larger percentage of the bills than formerly within the prescribed time, and with much less trouble and friction. A number of legal lights in the town claim we have no right to charge a percentage on a minimum rate which is paid in advance. I don't know whether we have or not, but it certainly facilitates the collection of the bills, and I had hoped that this paper might touch upon that point. Perhaps, however, some of the gentlemen present can enlighten me on the subject.

There is one method of collecting meter rates that has not yet been mentioned, that seems to me is capable of more general application than any other, and that is by making a charge for the first 1,000 gallons or 1,000 cubic feet sufficient to cover the

cost of installing the meter, making repairs, reading it, and keeping the accounts, and then a flat rate for the balance of the water supplied. That applies to a certain extent the principle of the difference between a wholesale and retail business, and it seems to be a fairer way than making a sliding schedule by which there is a chance to obtain more water for a less price. If there is any gentleman who can give any light with regard to collecting minimum rates in advance, I should be obliged for the information.

Mr. Hazen. I have been figuring some time on this matter of meter rates, and there is one improvement as it appears to me on the method which has just been suggested of charging a certain price for the first 1,000 gallons and a flat rate for all water in addition. The improvement is a very simple one. It consists in making a charge for each service, and a charge for all water used in addition always at the same rate. For instance, you make a charge of $3 a year for each service whether any water is used or not, and in addition you charge ten cents per 1,000 gallons, or whatever the rate may be, for all the water that is used. I believe that is a very fair way, easily computed and convenient. The amount to be charged per tap and the amount per 1,000 gallons of course require to be fixed in each case and depend upon a good many conditions. Milwaukee is the only American city which has adopted this scheme, so far as I remember. It was adopted in Berlin last April, after a very thorough discussion of the subject and after a large number of meter rates had been suggested.

Mr. Sullivan. I would like to ask the last speaker if he considers that a person using a greater amount of water should pay as much proportionally as a person using a less amount?

Mr. Hazen. That is a matter of policy. On the plan which I suggest, if a person uses at the meter rate $3 worth of water per annum, and the tap charge was $3, he would pay only $6, which is twice as much in proportion for the water as a large consumer. For other quantities of water the proportions would be different. A small consumer pays more relatively than a large consumer, and I think that is right, and I think the method suggested is a convenient one for getting at it.

Mr. Thomas, of Hingham. I was talking with a gentleman from New York last evening on this matter of meter charges, and it seemed to me he covered this point exactly. He said they charged so much for the first 10,000 gallons, say 20 cents a thousand; for

the second 10,000, 18 cents; and for the third 10,000, 16 cents, or whatever the price might be. Thus each consumer pays the same for the same amount of water. The domestic consumer pays the same as the manufacturer for a certain amount of water, 10,000 gallons, perhaps, a year, or whatever the amount may be. Then if the manufacturer uses more water he gets it cheaper, but for the same amount of water that the domestic consumer uses he pays the same. It seemed to me that was a very fair way.

Mr. Sullivan. I would say, Mr. President, that that is our method. We charge so much for meter rental, a per cent on the cost of it, and we charge fifteen cents per 1,000 gallons for the first 10,000 gallons, and for the second 10,000 gallons we charge at the rate of ten cents, and for all over 20,000 gallons we charge at the rate of five cents, which gives the larger consumer the advantage in getting a lower rate for all the water over 20,000 gallons he consumes during the month.

Mr. Russell. We have in Ilion just that system. It occurs to me that the whole meter question is very largely one of expediency and policy in the different localities. What might be a good policy in the city of Syracuse might be a very poor policy in the village of Ilion, where I live. And as to fire protection, our policy is to encourage the manufacturers. When we put in our mains we said to the manufacturers: "We will carry a cast iron branch to the curb, and you can extend it into your works and put on as many fire hydrants to be used exclusively for fire purposes as you choose. We don't want your factory to burn up. Put in your automatic system, too; it will cost you nothing for the water, and it will cost us simply the filling of it if you have no fire." Then comes in, of course, the moral question, Can we trust these men to be in connection with our water works, unless we put on a meter which is supposed never to register except in case of a fire? If you have perfect confidence in the manufacturers you don't care to put meters on; but if there is a large number of manufacturers, and among them some that you feel you cannot trust, then the question comes up in that locality.

Mr. Whitney. Did I understand Mr. Hawley to say that he makes no annual charge for the meters he sets?

Mr. Hawley. I make no charge for them.

Mr. Whitney. I think in a large majority of cases where the city owns the meters a charge is made of at least enough to cover the estimated cost of maintenance and possibly renewal of the meters

at some time. That charge, I think, is generally figured at about ten per cent. A great many places charge that, and I think they can hardly afford to do it for less than that.

Mr. Hawley. That question has come up several times. Our council insists that we shall sell water at a flat rate. "The poor man must be served at the same rate the rich man is" is the argument. It was necessary to stop the waste in certain places, and so we put in meters without charge wherever we thought we could stop it. And then there comes up the question of the cost of providing water for a large consumer, for instance, one using, we will say, a million gallons. We have only in his case one meter to maintain and one account to keep, while for a million gallons sold to a hundred small consumers we will have a hundred times the work to do in making repairs, reading the meters, and keeping the accounts. I think if that is all included in the cost of the first 1,000 gallons, and then a flat rate charged for additional water, it will put the thing on an equitable basis, and we will be paid not only for the water, but for the expense of maintaining the meter and keeping the account.

Mr. McKenzie. If my memory serves me correctly, this matter of flat rates or uniform meter rates for water was discussed at the meeting of the American Water Works Association, and it was stated by a superintendent, I think from Youngstown, Ohio, that they had established a meter rate on a sliding scale, so that the Pennsylvania Railroad Company, which took a large amount of water, got a rate approximating five cents per 1,000 gallons, while the ordinary rate for householders was twenty-five cents per 1,000 gallons; and that some of the householders had appealed the matter of the collection of these rates and the court has decided that the water department could not collect more from one than from another consumer, but that they must make a uniform rate and that the uniform rate must be the minimum rate. Now that matter may possibly come up in connection with some works with which I am connected. For instance, we sell water at eight cents per 1,000 gallons to large manufacturers, and we have a rate of twenty-five cents per 1,000 gallons for householders. One very wealthy man in town wants to take the water and is going to put in a meter, and he says that he shall not pay any more than other people pay, that his money is just as good as anybody's, and if other people get the water for eight cents per 1,000 gallons he won't pay any more. Now of course we might go to an attorney and pay a large amount of money for an

opinion as to whether we can adopt a sliding scale with a high rate for one and a low rate for another and collect, but I thought there might be somebody here who had had similar experience or who might know of any legal decisions in that line.

Mr. Walker. My experience is that you can't look after your meters short of $15 a year. We do it for $12, but it does n't pay us. Nobody can put in a lot of meters and go to them and read them once a month for $12 a year, but that is our minimum rate; we have that or nothing, and it is just the same whether they use a large amount or a small amount of water. If there is anything which makes tribulation it is a meter. [Laughter.] There is nothing that will kick like a man who thinks he is going to save two or three dollars by having a meter put on and then finds that his first bill amounts to as much as he has been paying in a year. I have seen them when I thought they would go through the roof. [Laughter.] I tell you what it is, we have the most trouble with those folks who insist upon having a meter. They say they don't use much water, and they can just as well save $3 a year as to let the city have it; so we put on the meter and the first quarter perhaps the bill is $8, and then if there is n't a hot time in the old town I hope to die. [Laughter.]

Mr. Bancroft. In our town we make a minimum charge of $6 a year, and that gives the consumer about 16,000 gallons of water. For the next 100,000 gallons he pays thirty cents a thousand; for the next 200,000 gallons he pays twenty-five cents a thousand; and the price for all he uses in excess of that amount is twenty cents a thousand. Our minimum rate is collected semi-annually, $3 each six months in advance.

Mr. Whitney. In reference to the matter of which Mr. McKenzie spoke, there is no question but what under Massachusetts laws he would have a perfect right to establish such rates as he saw fit. Under Connecticut laws I should think it depended altogether on the wording of the charter of the particular private company to which he refers.

Mr. McKenzie. The charter simply says the directors may establish "reasonable rates." [Laughter.]

Mr. Whitney. I suppose that one little word "reasonable" makes all the trouble.

Mr. McKenzie. Nearly all our water works charters are worded in that way.

FLOOD-WATER CHANNEL OF THE ALTOONA, PA., RESERVOIRS.

BY CHARLES W. KNIGHT, C.E.

[*Read September 13, 1899.*]

The Altoona, Pa., storage reservoirs are located on Burgoons' Run, six miles west of the city, near Kittanning Point station on the main line of the Pennsylvania railroad. Burgoons' Run is made up at this point of two streams coming down the eastern slope of the Allegheny Mountains. Just below the fork is the upper basin and 3,000 feet beyond is the embankment of the lower reservoir. The flow-line of the upper basin is 1,496.4 feet above tide water, with an area of water surface of 12.6 acres and a capacity of 65,000,000 gallons; and the flow-line of the lower basin is 1,435 feet above tide water, with an area of 36.47 acres and a capacity of 356,000,000 gallons. The distributing system of Altoona is divided into a high and a low service, and these reservoirs are used separately for the two services. The low service is fed through a distributing reservoir within the city, while the high is at present fed directly from the Kittanning Point basin.

The upper reservoir was built in 1887 and the lower in 1894, 1895, and 1896. The flood-water channel was completed in 1897. Previous to the completion of this channel the city had expended about $20,000 in removing some of the more objectionable accumulations brought down the valleys by the floods and deposited in the upper basin. The material washed down consisted of driftwood, sawdust, coke cinder, sand, and gravel. To prevent this reservoir from becoming practically useless in the near future the flood-water channel became a necessity. The amount of material washed into this reservoir had exceeded 20,000 cubic yards in one day, and the flood-water channel was built for the purpose of keeping out this, as well as water heavily charged with sand, soil, and a great amount of vegetable matter that came down the mountain slopes during severe storms, reducing the storage capacity each year by a considerable percentage, as well as impairing the quality of the water.

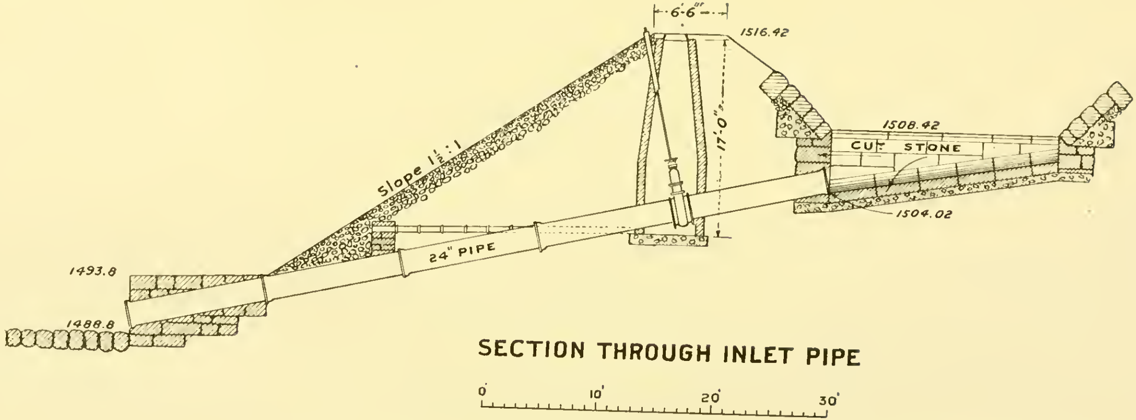
Fig. 1. — General View of Reservoirs and Flood-water Channel, Altoona, Pa.

The flood-water channel proper is 3,991 feet in length, but the necessary constructions to turn the water into it above the upper reservoir and return it again to the creek channel below the lower reservoir make the total length 5,630 feet. There is first a diverting embankment 877 feet long across the valley just above the upper reservoir; then comes the main channel, at the lower end of which is the by-wash channel 259 feet long, where the water falls to the level of the valley below the lower reservoir; and finally there is a walled, curved channel 503 feet long, in which the velocity of the current is reduced, and which turns the stream into the old channel in its normal condition. A plan of the work is shown on the folded plate, and a general view of the reservoirs and flood-water channel in Fig. 1.

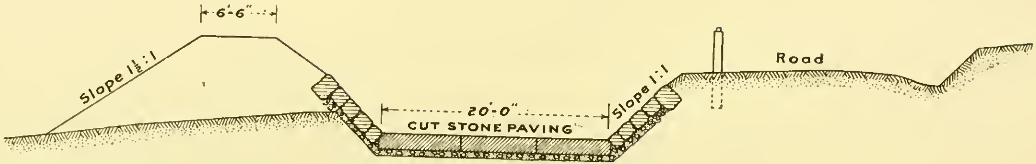
The walled channel is 60 feet in width, increasing to this width on the apron at the foot of the by-wash from 16 feet, which is the width of the straight portion of the by-wash. The curved part of the by-wash is gradually increased in width to 20 feet at the bottom. The flood channel proper is 20 feet wide at the bottom, with side slopes of one to one and a bottom grade of two feet per hundred for its entire length, and its depth is eight feet. The location of the channel was so chosen as to have its bottom in cut where practicable. All of the masonry of this work was of local sandstone. The bottom of the channel is of dressed stone 15 inches in depth, with ¼-inch joints, on a foundation of 6 inches of concrete. (See Figs. 3 and 4.) The side slopes are paved for the first 3 feet with rock-faced ashlar on a backing of 6 inches of concrete, and for two feet more with a close jointed dry wall; the remainder of the side slopes are in earth. When embankment was required it was built up in 6-inch layers wetted and well rolled. The material excavated was mostly clay and compact sand with small stones and fragments of rock imbedded in it.

The diverting embankment is entirely of earth protected by a slope wall on its up-stream face and by broken stone on the lower slope. Under this embankment is a puddle core wall starting from an impervious stratum and carried up to its base. The material in this embankment was placed in the same way as on the embankment of the flood channel, and its top has a grade of one foot per hundred for the entire length from the head of the flood-water channel.

At the highest part of this diverting embankment near the old creek bed were placed two lines of 30-inch cast iron pipe with



SECTION THROUGH INLET PIPE



SECTION OF FLOOD WATER CHANNEL

FIGS. 2 AND 3.

masonry inlet for passing the stream during the construction of the embankment; and at the point where the embankment joins the flood-water channel proper, forming the throat of the channel, is an emergency spillway 100 feet in length, built of heavy blocks of stone laid dry, with its top or overfall 6 feet above the bottom of the flood channel (Fig. 5).

At its head and extending entirely across the flood-water channel is a sunken masonry chamber with segmental bottom inclined towards the reservoir, having its outlet through a 24-inch cast iron pipe leading down into the upper reservoir and controlled by a valve.

FIG. 4.—FLOOD-WATER CHANNEL.

This chamber is 2½ feet wide and is covered with a heavy iron grating. This structure forms the inlet for all the water let into the reservoirs, as the supply for the lower basin passes first through the upper reservoir (Figs. 2 and 5).

Where the flood-water channel passes the lower end of the upper reservoir is another emergency spillway 50 feet long, with its overfall 1.3 feet higher than the regular spillway of this reservoir and 5.5 feet above the bottom of the flood channel.

FIG. 5. — EMERGENCY SPILLWAY AT THROAT OF FLOOD-WATER CHANNEL, AND INLET TO UPPER RESERVOIR.

FIG. 6. — INLET TOWER AND SPILLWAY, LOWER RESERVOIR.

Adjoining the spillway of the lower basin (Fig. 6), which is 25 feet long and built entirely of masonry, is a third emergency spillway 100 feet in length, with its overfall one foot above that of the regular spillway (Fig. 7). All of these emergency spillways are earth embankments faced with dry walls on the reservoir side, with rubble masonry on concrete backings on the channel side, and with their top paving laid in clay puddle and the cracks filled with fine sand and screenings from the stone crusher.

Fig. 8 is a view of the dam of the lower reservoir, a cross section

FIG. 7. — EMERGENCY SPILLWAY, LOWER RESERVOIR.

of which is shown in Fig. 9. Fig. 10 is a view of the by-wash channel.

Whenever the mountain water is turbid the valve on the pipe at the head of the flood channel is closed. Except after a few storms following long dry spells in the summer this turbidity does not occur unless the rate of flow exceeds 50,000,000 gallons per day, or after heavy floods; when the flow is again reduced to such an amount that the stream becomes clear, the valve is opened. The inlet to the upper reservoir from the head of the flood channel and the regular spillway of the lower reservoir were designed to pass 50,000,000

gallons per day before any water would pass down the flood-water channel or over the emergency spillway of the lower reservoir.

The construction of the three emergency spillways was due mainly to observation of the action of Burgoons' Run and the possibility of temporary clogging of the throat of the flood-water channel rather than to computations from the greatest rainfalls.

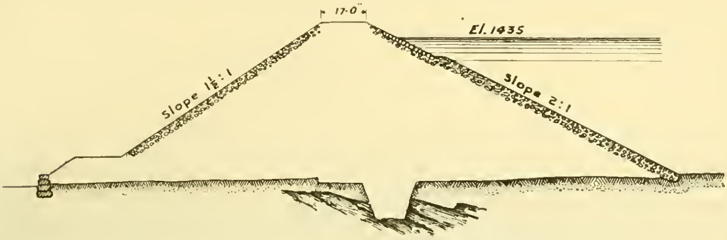
At the time of a flood in May, 1894, the water flowed over the top of the embankment of the upper reservoir for about fifteen minutes, on account of the sudden release of large volumes of water

FIG. 8.—GENERAL VIEW OF DAM, LOWER RESERVOIR, ALTOONA, PA.

which had been temporarily dammed at the railroad culverts about 1,000 feet above this reservoir. Although previous to this greater rainfalls had occurred, yet the one of 1894 caused the highest water in the reservoir.

Similar action had been noticed in former years, as on several occasions great flood waves had been observed rolling down the valley and into the reservoir, causing its surface to rise 2 or 3 feet in a few minutes and as quickly subside. What is generally known

as the horseshoe curve of the Pennsylvania railroad lies across the valleys of the two streams which unite in the upper reservoir on an embankment about 100 feet high, through which the streams pass in arched culverts of 20-feet span. The one that was dammed in 1894 is double, having a waterway 40 feet in width. The water rose to a dangerous height before the flood dam gave way, causing the wave that overtopped the reservoir embankment.



SECTION OF DAM LOWER RESERVOIR

FIG. 9.

Almost the entire watershed of the streams above the reservoirs is covered with a second growth of trees, while on the mountain slopes and along the valleys lie millions of feet of old logs and trees, great and small, in various conditions of decay, which are gradually sliding down into the stream channel and then more rapidly passing down stream during high water, causing numerous dams, several of which may sometime give way simultaneously and cause large flood waves with ordinary precipitation.

The watershed above these reservoirs has an area of 9.6 square miles, mostly steep mountain slopes, from which at certain seasons at least two thirds of the precipitation will flow off within 24 hours after a storm. The heaviest rainfall known in that vicinity has been about 8 inches in 24 hours on an adjoining watershed, which might mean a constant flow for that time of about 1,500 cubic feet per second. This was during the great flood of 1889; but the flood of 1894, when there was only about 5 inches of rainfall in two days, as recorded, produced a flood volume of about 3,000 cubic feet per second for about 15 minutes, when the upper reservoir embankment was overtopped by the breaking away of flood dams as before mentioned. While such a flood wave may never again be produced,

especially as the Water Commissioners of the city of Altoona are gradually burning the old logs along the creek channels, yet it seemed reasonable to provide a capacity of flood channel equal to the greatest observed volume with a factor of safety against momentary choking at its throat; hence also the construction of the emergency spillways.

In such constructions there are questions that are secondary in importance only to those already considered, such as durability of such a channel and its permanency of operation.

It will be observed that in heavy storms with a normal flow, the

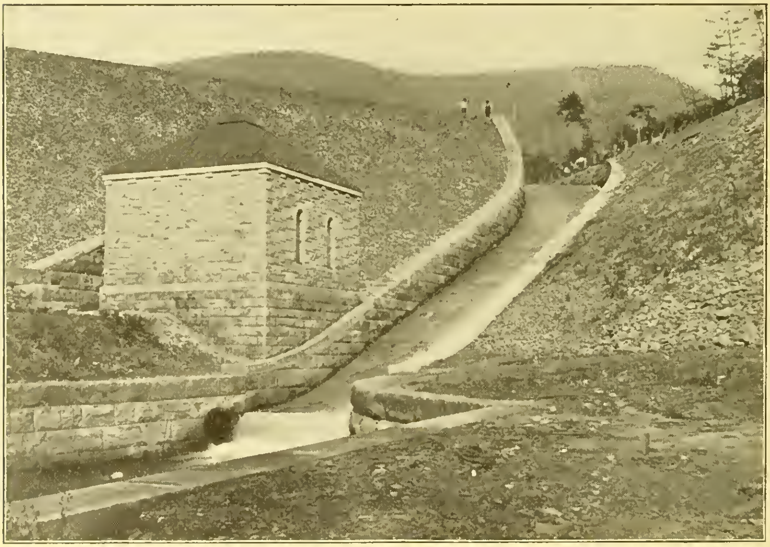


FIG. 10. — BY-WASH CHANNEL, AND GATE HOUSE OF LOWER RESERVOIR.

velocity of the current in the channel will average about 22 feet per second, and at the time of some of the flood waves it may reach 27 feet per second. At such times large quantities of sand, gravel, and large stones are being carried down the valley, and must either lodge in the basin formed by the diverting embankment or pass through the channel. The former will be the case until such a grade has been formed that the force of the water in the greater floods will

carry practically everything that may be washed down the valley into the mouth of the flood channel, where it will be quickly conveyed to the creek below the lower reservoir.

Although the grade of the creek channels up the valleys exceeds 3 feet per hundred, yet on account of the irregularities of their channels and the lesser volumes of water flowing, they do not appear to possess more transporting power than a grade of about one foot per hundred with the double volume of water after the streams unite.

While this fact may be said to be proved to some extent by actual experiments, yet the grade adopted for the top of the diverting embankment was more or less empirical, as it was the result of local observation on the disposition of the material washed down from the valleys. Although a one per cent grade was considered ample to keep it from being overtopped by accumulations in the basin above it, yet its alignment was so arranged as to admit of the slope being made greater, if this ever became necessary, without reconstruction.

The flood-water channel with all its accessories cost about $90,000, or about $16 per lineal foot, by contract at generally fair prices, and the result has been a decided improvement in the taste and appearance of the water, if not in its sanitary condition, and the full storage capacities of the basins will be maintained.

Questions of economy of construction and most perfect operation controlled in the adoption of a uniform section for the flood channel proper, and when the elevation and position of the embankment of the lower basin was known the grade became practically fixed. While a much less grade would have kept the channel free from all accumulations, yet good reason for the plan adopted is readily found when it is considered that the velocity of water cannot be materially accelerated or retarded in such constructions without increased cost. Configuration of the ground may make such a rule inapplicable in some situations; it, however, deserves serious consideration before setting it aside.

It is hardly necessary to remark that storage reservoirs for domestic water supplies constructed in mountain ravines where the wash is considerable should have a flood-water channel of sufficient capacity to exclude the entire flood volume, and that the carrying capacity should be based rather upon observed flood volumes than upon records of maximum precipitation.

To determine even approximately the probable flood volumes from

a watershed, observations of maximum precipitation are not likely to be applicable unless made over the territory under consideration. This will be better understood when we consider that the rainfall on May 30 and 31, 1889, which was considered a general storm, near the city of Altoona on the eastern slope of the Allegheny Mountains, in a distance of less than 10 miles varied between 2 and 6 inches, and within a distance of less than 20 miles, passing over the mountains, it ranged between 2 and more than 8 inches in 24 hours. These observations apply particularly to small and mountainous watersheds.

This flood-water channel and the storage basins protected by it were designed by and constructed under the supervision of the engineers comprising the Stanwix Engineering Co.

COMPARISON BETWEEN HIGH AND LOW DUTY PUMPING ENGINES ON A SMALL WATER WORKS PLANT.

BY JOHN E. SMITH, SUPERINTENDENT, ANDOVER, MASS.

(*Read December 14, 1898.*)

Mr. President and Members of the New England Water Works Association:

Gentlemen, — Being known to many of you as a crank on the rotative type of high duty pumping engine for water works service, I wish to assure you that I am not going to tire you with any pet hobby; the few facts which I wish to present are abstracted from reports made to the Andover Water Commissioners covering the years 1895, 1896, and 1897.

As conditions to be met constitute a vital element in any problem, a brief description of the Andover Water Works system will better enable you to judge whether the improvements made in the pumping plant at Andover will prove of equal value in other places.

Haggett's Pond, the source of supply, is at an elevation of 104 feet above mean high water, and five miles distant and on the opposite side of the town from the distributing reservoir. The elevation of the water in this reservoir when full is 309 feet, giving a static head at the pond of 205 feet. The force main is a 12-inch cast iron pipe, which is also the backbone of the distributing system, so that with the pumps running, the system is supplied directly, the surplus pumpage overflowing into the reservoir.

This force main crosses the valley of the Shawsheen River at an elevation of 35 feet, or 69 feet below pond level; there are three summits between the pond and the town, the highest being at an elevation of 168 feet, or 64 feet above pond level.

With the pumps running at their normal capacity, the velocity of the water in this force main is 3½ feet per second and the frictional loss of head is about 125 feet. Thus it is evident that the element of safety of the pumping plant is equally important with that of economy. It requires no argument to show that any considerable

draft of water in the Shawsheen valley, 69 feet below the pond level, will cause a very considerable drop in the pressure from the dynamic head of 330 feet under which the pumps are running. A direct acting pump (unless throttled) can only be adjusted by increase of piston speed with consequent dangers.

In the Andover system it was thoroughly demonstrated, within a few months, that it was neither safe nor economical to run a 12 x 24 x 12 x 18 inch compound duplex pump with but a single attendant at the pumping station. With the pump running at full speed it was not safe for the engineer to go 20 feet away from the pump. With every precaution which could be taken, the danger of depending upon one pump in operating such a system was considered too great. Having learned wisdom from experience, we called for designs and proposals from a number of the most reputable builders of pumping machinery, and erected a vertical, cross-compound crank and fly-wheel pumping engine.

Though I should be pleased to answer any questions in regard to this engine, it would be superfluous to enter into a description of it. It is sufficient to say that it is easily controlled and its speed is automatically governed.

With this type of engine the dangers existing in operating the direct acting pump are entirely overcome. A draft of any amount of water in any part of the system is automatically cared for, and the pumping station is now operated by one attendant with less work and worry than formerly when two men were employed.

The following incident will illustrate the difference in the amount of attention required. About six weeks ago a 6-inch blow-off gate on the force main, at an elevation of 39 feet, blew out while the pumps were running at their normal capacity. The draft was so great that no water could be obtained at an elevation of 156 feet, yet although the gage showed a drop of pressure from 130 to 40 pounds, the engine did not vary one revolution per minute in speed, and it was some minutes before the engineer realized that something had happened.

As regards safety and convenience, the crank and fly-wheel type of engine has certainly been very successful at Andover; the showing as regards economy has been equally satisfactory.

The expense of operating the direct acting duplex pump for the year 1895, when the quantity pumped was, according to displacement, 117,857,305 gallons, was as follows: —

Fuel	$1,186.07
Attendance	1,203.96
Oil, waste, and supplies	106.33
Total	$2,496.36

In 1897 the total expense of operating the crank and fly-wheel engine 1,471.5 hours and the direct acting pump 203.5 hours was : —

Fuel	$750.88
Attendance	926.25
Oil, waste, and supplies	213.15
Total	$1,890.28

or $606.08 less than the total expense in 1895.

The cost per million gallons was $21.18 in 1895 and $16.33 in 1897, showing a saving of $4.85 per million gallons. Taking the year 1897 only, the direct acting pump was run 203.5 hours, with a coal consumption of 53,100 pounds or 261 pounds per hour, while the crank and fly-wheel engine was run 1,471.5 hours, with a coal consumption of 228,190 pounds or 155 pounds per hour — a saving of 106 pounds of coal per hour.

Perhaps a better comparison is obtained by computing the cost of operation of the two pumps, taking an average figure for the price of coal. The total running time in 1897 was 1,675 hours. In this time the saving in coal by using the crank and fly-wheel engine instead of the direct acting pump would be 177,550 pounds, or about 79 tons. Taking the cost of coal as $4.50 per ton in the shed, the saving in fuel would amount to $355.50 for the year. The actual saving in attendance in 1897 over 1895 was $277.77, while the cost of oil and supplies was $106.72 more in 1897 than in 1895. This makes the total saving for the year $526.55.

The cost of installing the direct acting pump was		$ 9,041.44
,, ,, ,, ,, ,, crank and fly-wheel engine was		13,368.36
Difference		$4,326.92
Interest on difference, at 4 per cent	$173.08	
Five per cent depreciation on difference	216.35	
	$389.43	

Subtracting these figures from the saving of $526.55 in running expenses shows a net annual saving of $137.12 in favor of the crank and fly-wheel engine. As the quantity of water pumped increases, this saving will be largely increased.

The smaller water works plants are frequently, it seems to me, constructed without sufficient investigation into the relative economy of the different kinds of machinery required. The first cost is often the only consideration. At the present time any device or appliance which will save 4 per cent interest and a reasonable depreciation on its cost is a judicious investment, and it is false economy to install any appliance solely because its first cost is small.

DISCUSSION.

MR. QUINN. I would like to find out from Mr. Smith how he regulates the speed of a crank and fly-wheel engine, and also of the direct acting engine?

MR. SMITH. The speed of the crank and fly-wheel engine is reduced automatically by the governor, and it also cuts off shorter on the high pressure cylinder. It really creates a back pressure or reverse curve on the card. It is only momentary. In regulating the speed of the direct acting engine, there are three ways to do it: by the cushion valves, by the throttle valve, or by the cross-exhaust. The last is of course an expensive way. If you use your cushion valves you have got to jump around pretty lively on a quick change of speed. By the throttle valve is the only way it can be done practically.

MR. GEORGE J. FORAN. Mr. Smith, perhaps unintentionally, demonstrates that under ordinary conditions his *high duty pumping engine* would not, at least to date, have proved a paying investment. I go still farther; it ought not to be even at Andover. I have taken up this discussion, believing it to be, in the long run, as important to the salesman or manufacturer as to the members of this Association, purchasers and operators of pumping engines, that all claims for the superiority of the high duty engine should rest upon a solid, unequivocal basis.

First. Mr. Smith essays to show that IF his high duty engine exclusively had done the pumping for 1897, a net saving of $137.12 would have resulted, above the cost for operating the direct acting engine, taking into account difference in investment, interest, depre-

ciation, attendance, etc.; to obtain this figure the high duty engine is credited with a saving of $277.77 in attendance, because, we are told, the unusual severity of the service renders the operation of a direct acting engine unsafe without extra attendance; that is to say, under ordinary conditions had the high duty engine done the entire pumping, a net *loss* of $140.65 ($277.77 — $137.12) would have resulted, even at the same cost for attendance. It would be an insult to the intelligence of this Association to discuss the relative cost of attendance upon a high duty and direct acting engine under ordinary conditions — we all know the loss would be even greater than stated above, and without doubt, Mr. Smith would agree with this statement.

Second. Mr. Smith's comparison of the two engines with the resultant condemnation of the direct acting as unsafe is absolutely unjust. Here is a service claimed to be unusually severe, for which certainly some regulation should be provided — the high duty engine is fitted with its governor which fulfills this requirement, and, in answer to a question, Mr. Smith states the direct acting engine is "regulated by the throttle, the cushion valves, and the cross-exhaust" — in other words, when something happens, the attendant who is obliged to stay near by for that purpose jumps to the direct acting engine and attempts to adjust it. An automatic device would be cheaper. It is quite certain if the fly-wheel engine were similarly operated without a governor, extra attendants would be desirable if they could be induced to stay in the station. It is equally certain that a device for automatically regulating the direct acting engine could be attached which would render it absolutely safe — so simple as to offer no difficulties to any member of this Association, and so cheap as not to be worth considering as a modifying investment. This places the Andover plant on the same basis as an ordinary plant as regards attendance.

The remainder of this discussion is not essential to the main facts above stated. Space will not permit of a detailed criticism, but I would like to bring up a few points of interest.

(*a*) In 1897 the engines pumped 259 days or 1,675 hours in all, that is, approximately, 6½ hours per day of pumping. It seems too bad the direct acting engine should have pumped 203½ hours of this time. The yearly report partially explains this, as, according to the original contract, the high duty engine was "taken down and examined for wear in its various parts and found in excellent condi-

tion" ; nevertheless, the actual figures for 1897 are seen to be different from the assumption in Mr. Smith's paper. This may never happen again, but it will be just as well to retain the direct acting engine "in case."

(*b*) "The danger of depending upon one pump in operating a system like this was considered too great," etc. Had a second direct acting engine been bought, the price would have been considerably less than for the first. Nevertheless, the difference in investment (presumably including foundations) is based upon the price of the first engine with no deduction for depreciation. Properly considered, this makes the showing still worse. (See *d*.)

(*c*) Depreciation is figured upon the difference of investment. It is questionable whether both types should be figured at the same depreciation. Depreciation is dependent upon several conditions — principally wear and tear and permanency — and the wear and tear on an engine not in use is not excessive. However, this is unimportant. Presumably the new [high duty] engine will be in active service longer than the first — in this connection it would be interesting to know the depreciation allowed on the first engine. That investment has doubtless been transferred very properly to some other account. (See *d*.)

(*d*) Briefly, the first engine is no longer an active producer. The interest and depreciation upon its value must be earned by the new engine, but is chargeable to insurance or guarantee of safety, or some similar account. It has ceased to be a direct earning investment. If, for argument, Mr. Smith desires to show what the direct acting engine would have done in 1897 if no new engine had been bought, he must give it full credit for all depreciation up to that time. He would hardly want to do this, and it is hardly fair. A second engine had to be bought, and the real question is, What was the result of buying a high duty rather than direct acting engine? In that discussion we must compare the costs of the two engines if bought at the same time under the same conditions, putting them on a level basis regarding depreciation, conditions of market, and competition.

(*e*) Referring to the various Andover reports, I estimate the duty of the direct acting engine for 1897 is not quite so good as in previous years, possibly because working against somewhat higher pressure than designed for, possibly because lack of attendance would not permit of best results; in July and August, however, the work-

ing duty for the high duty engine was over 142,000,000 foot pounds per 100 pounds of coal — so very satisfactory for an engine of 1,750,000 gallons capacity as to lead to doubts of its accuracy.

(*f*) There are many points upon which Mr. Smith could give us interesting information: the efficiency of the boilers; a few cards from the water pressure recording gage, with statements as to variation in pressure and consumption at various levels in the system, and an analysis of the increase in water pressure. The last six months of 1891 the average velocity of pumping was 1,247 gallons per minute; in 1893 it was 1,156.6; in 1897, 1,152. The pressure heads were as follows: in 1891, 300 feet for five of the six months; 1893, 300 feet every month; 1897, 330 feet nine months of the year, with a yearly average of 326.4 feet. Is this increase of head between 1893 and 1897 due to tuberculation of the pipes or changes in the method of distribution, or have the consumers moved up on the hills in anticipation of a flood when a water main bursts some day and the engine and engineer continue working in blissful ignorance of the disaster? Pumping at a less rate with larger consumption in 1897, the friction would be less than in 1891, condition of pipe, reservoir levels, and distribution remaining the same. Are the given pressures maximum or average? (The original total static head was 204.5 feet from ordinary high water in pond to high water in reservoir.) If not maximum, what is the maximum pressure? This materially affects the service and duty. The pressures are very uniform, remarkably so for a system "so difficult of operation" and with such varying pressures, or perhaps most of the consumers are at the highest level, thus rendering the amounts drawn at other levels of small importance, in which case the difficulties of pumping are not so great after all, except for some impulse on the part of the water to worry the engine *à la* Kipling. Gates have blown out in other plants without fatal results. I can endorse Mr. Smith's statement that his engineer might not notice a slight change in the speed of the high duty engine, as, when I first entered the station last summer, he was not in the building, although the engine was in operation. He did come in immediately, however, and did not seem to be worrying.

Mr. Smith. I believe I stated the position fairly in opening my paper. Mr. Foran should have understood that under ordinary conditions I believe that each type of pump must stand on its own merits until the saving in running expenses will equal 4 per cent on

the investment, and the question is one of finances wholly. I tried to bring out the fact strongly that the question of regulation was a great factor in favor of a rotative type of pump for the Andover system. Two men are still employed at the pumping station when the direct acting pumps are used; if but one attendant had been employed the expense for attendance would have been $720, or a saving of $206 more than is shown in the paper. Mr. Foran admits the need of a regulating appliance and says that a regulating device can be applied, so simple as to offer no difficulties and so cheap as not to require consideration as an investment. I confess myself dull, but I cannot conceive of such an appliance. Further, the specifications under which the high duty pump was called for gave any builder a chance to propose a direct acting pump with such a device; and although the firm with which Mr. Foran is connected submitted several proposals, no such device is mentioned by them. To go still further, when Mr. Foran or any one else has such a device which shall have been proven able to automatically adjust the speed and length of stroke of a direct acting pump, the town of Andover will be glad to purchase and install it on the direct acting pump.

The remainder of Mr. Foran's discussion has no essential bearing. I will state, however, that he labors under a wrong impression in regard to the direct acting pump at Andover, as it has never been out of commission except for repairs. As for depreciation, the cost of repairs in the case of the direct acting pump during five years of service was over 15 per cent of the first cost. The high duty pump has been in operation three years, and the cost of repairs has been almost nothing and the wear insignificant. Of the cause of the increased frictional resistance with the high duty pump running, to which Mr. Foran refers, I cannot be positive, as there have never been any weir measurements of the capacity of either pump. I can simply say that from observation I should ascribe it to there being less slip from the high duty pump and less accumulation of air in the water cylinders. It is certainly not due to any condition of the system or service, as the same change takes place at the present time and a higher lift is shown when operating the high duty pump. Another curious feature of the case is that the apparent consumption of water is less when the high duty pump is used. It should be borne in mind that all figures are made on the basis of displacement without allowance for slip.

A TEST OF THE NEW PUMPING ENGINE AT WALTHAM, MASS.

BY DEAN & MAIN, MECHANICAL ENGINEERS.

(*Boston, Mass., November 19, 1898.*)

The engine is a cross compound horizontal fly-wheel engine with steam jackets and re-heater, having horizontal double acting pumps located behind the steam cylinders and driven by extensions of the steam piston rods. The steam cylinders have Corliss valves. A centrifugal governor determines the point of cut-off of the high pressure valves. The low pressure cut-off is determined by hand.

The guaranteed duty of 110,000,000 foot pounds was based upon the consumption of 1,000 pounds of dry steam.

The test was made by weighing the feed water into the boiler. Near the throttle valve the steam passed through a separator and the water collected there was weighed. Between the separator and the throttle valve a calorimeter was inserted and the moisture left by the separator determined. The waste of the calorimeter was weighed with the separator drain.

The jacket and re-heater drains were allowed to run to waste.

All pipes were disconnected in such a way as to properly account for all steam and water in the system.

The duration of the test was eight hours, which is two hours less than intended, on account of an unanticipated delay in starting. As the duty was based on feed water this does not sensibly vitiate the accuracy of the test, for the hourly weights of feed water were determined and were practically equal.

PRINCIPAL DIMENSIONS.

Diameter of high pressure cylinder	22	inches
,, ,, low ,, ,,	48	,,
,, ,, each plunger	15	,,
Stroke of high pressure piston and plunger	$36\frac{1}{32}$	,,
,, ,, low ,, ,, ,, ,,	36	,,
Ratio of piston areas	4.76	

AVERAGE TEMPERATURES.

Of engine room	74°	Fahrenheit
,, external air	43°	,,
,, water in pump well	56°	,,

AVERAGE PRESSURES.

Of atmosphere by barometer	14.81	pounds
,, steam at engine by gage	111.47	,,
,, ,, ,, ,, absolute	126.28	,,
,, vacuum by gage	13.49	,,
,, force main by test gage	68.48	,,
Corresponding head above gage	158.19	feet
Average reading of float gage in pump well	14.47	,,
Distance between zero of float and center of gage on force main	4.28	,,
Total dynamic head	176.94	,,

STEAM USED BY ENGINE.

Total moist steam delivered to engine in eight hours	19,874	pounds
Water drained from separator, and calorimeter waste	538	,,
Steam delivered to throttle by separator	19,336	,,
Moisture in steam at throttle by calorimeter	1.32	per cent
Dry steam delivered to engine	19,081	pounds

WORK DONE BY ENGINE. — DUTY.

Average number of revolutions per minute	32.38	
Volume displaced by plungers in eight hours	222,737.74	cubic feet
Weight of same at 62.39 pounds per cubic foot	13,896,608	pounds
Work done by plunger in eight hours, 13,896,608 pounds × 176.94 feet =	2,458,865,819	foot pounds
Duty per 1,000 pounds of dry steam, 2,458,865,819 ÷ 19.081 =	128,865,000	,, ,,
Excess over guarantee, 18,865,000 foot pounds =	17.15	per cent
Work done by plungers per minute	5,122,638	foot pounds
Pump horse-power, 5,122,638 ÷ 33.000 =	155.23	horse-power
Indicated power of steam cylinders[1]	167.08	,,
Approximate friction of engine, 167.08 — 155.23 =	11.85	horse-power = 7.1 per cent
Approximate efficiency of mechanism	92.9	per cent

The engine was built to pump against about 273 feet dynamic head, instead of 176.94 feet, but this could not be obtained on account of projected extensions of the water works not having been carried out. Furthermore the boiler pressure of 150 pounds promised by the speci-

[1] This is approximate and was determined from only two sets of indicator diagrams.

fications could not be carried on account of the low head. The boiler pressure used was 113.1 pounds. If the pressure had been 150 pounds, the pressure at the engine would have been about 147.5 pounds by gage, or 162.3 pounds absolute, instead of 126.28 pounds absolute. On the principle that the steam consumption of an engine is nearly proportional to the logarithms of the steam pressures, the duty would have been about 135,000,000 foot pounds with the higher pressure. Moreover, if the greater head had existed, the duty would have been a little greater because less relative work would have been consumed by the friction of the engine and pumps.

On account of a slight derangement of a valve gear detail the engine was slowed down a little after running a few hours and averaged 0.95 of a revolution per minute, during the whole test, less than that required by the specifications, and therefore fell a little short of the required capacity. It had, however, on a sufficient number of other occasions shown its ability to give more than the normal capacity.

This engine is a good specimen of designing and building, possesses ample stability for reliable service, and the duty is among the highest recorded for compound engines.

Respectfully submitted,

(Signed) DEAN & MAIN.

ROCEEDINGS OF THE EIGHTEENTH ANNUAL CONVENTION.

September 13, 14, and 15, 1899.

On Tuesday, September 12, many of the members *en route* to the convention at Syracuse visited the new filter plant and pumping station at Albany, N. Y., which were explained by Mr. Allen Hazen, the designing and constructing engineer, and Mr. George I. Bailey, Superintendent of the Albany water works.

Syracuse, N. Y.,
September 13, 14, and 15, 1899.

The headquarters of the Association during the convention were at the Yates Hotel, and the meetings were held in Assembly Hall, on the fifth floor of the hotel building.

The following members and guests were in attendance: —

Active Members.

Charles H. Baldwin, Lewis M. Bancroft, George B. Bassett, Joseph E. Beals, James F. Bigelow, Forrest E. Bisbee, James W. Blackmer, George Bowers, Fred. Brooks, James Burnie, William F. Codd, Charles D. Colson, Byron I. Cook, Henry A. Cook, F. H. Crandall, George K. Crandall, J. W. Crawford, George E. Crowell, William E. Davis, William Downey, E. R. Dyer, F. F. Forbes, J. H. Gamwell, D. H. Gilderson, Albert S. Glover, Amos A. Gould, Fred. W. Gow, John C. Haskell, L. M. Hastings, W. C. Hawley, Allen Hazen, W. R. Hill, James A. Huntington, William S. Johnson, Willard Kent, Patrick Kieran, Louis H. Knapp, Harry A. Lord, A. E. Martin, Leonard Metcalf, Thomas Naylor, F. L. Northrop, W. Paulison, John H. Perkins, J. B. Putnam, A. H. Salisbury, M. A. Sinclair, H. O. Smith, H. T. Sparks, George A. Stacy, J. C. Sullivan, J. G. Tenney, R. J. Thomas, William H. Thomas, John Venner, C. K. Walker, E. L. Wallace, John C. Whitney, George E. Winslow, E. T. Wiswall — 60.

Honorary Member.

F. W. Shepperd — 1.

Associate Members.

Coffin Valve Co., by H. L. Weston; Hersey Mfg. Co., by J. A. Tilden, Samuel Harrison, and Fred A. Smith; National Meter Co., by J. G. Lutkin; Neptune Meter Co., by D. B. McCarthy; New York Filter Mfg. Co., by Charles Wilson; Pittsburg Meter Co., by F. H. Gillespie; Rensselaer Mfg. Co., by Fred. S. Yates; Ross Valve Co., by William Ross and J. C. Ross; A. P. Smith Mfg. Co., by W. H. Van Winkle; Thomson Meter Co., by S. D. Higley, Henry C. Folger, and E. J. Snow; Union Water Meter Co., by J. P. K. Otis; U. S. Cast Iron Pipe & Foundry Co., by A. H. Lang; H. R. Worthington, by H. S. Wilson and Joseph W. Roe — 19.

Guests.

E. A. Fuertes, W. E. Mott, Ithaca, N. Y.; Mrs. J. G. Tenney, Leominster, Mass.; John L. Wetherley, *Syracuse Journal;* Mrs. H. O. Smith, Leicester, Mass.: James Burns, Mrs. James Burns, Lynn, Mass.; Fred. C. Gamwell, Palmer, Mass.; Mrs. Joseph E. Beals, Middleboro, Mass.; Walter H. Sears, Plymouth, Mass.; Mrs. H. A. Lord, Ogdensburg, N. Y.; Mrs. F. S. Yates, Troy, N. Y.; Mrs. W. Paulison, Passaic, N. J.; Mrs. George A. Stacy, Mrs. N. Willard, Marlboro, Mass.; Mrs. Thomas Naylor, Maynard, Mass.; W. W. Trowbridge, West Newton, Mass.; L. M. Hudson, L. B. Lawrence, Thomas Burke, J. B. Wood, Edward S. Murphy, Marlboro, Mass.; C. E. Riley, Brookline, Mass.; G. S. Hook, Oneida, N. Y.; George F. Rowell and G. H. Patridge, *Engineering Record;* George E. Pickering, Boston, Mass.; Eddy Valve Co., by Robert Kinnear; Mrs. E. L. Wallace, F. G. Judkins, Mrs. F. G. Judkins, Franklin Falls, N. H.; Mrs. L. M. Hastings, Cambridge, Mass.; Mrs. George E. Winslow, Waltham, Mass.; William B. Littlefield, Mrs. Littlefield, Lynn, Mass.; William P. Baker, *Syracuse Herald;* Mrs. D. H. Gilderson, Haverhill, Mass.; Mrs. William F. Codd, Nantucket, Mass.; M. J. Dowd, August Fels, Mrs. Fels, Mrs. George Bowers, A. J. Barrett, Mrs. Barrett, Lowell, Mass.; Mrs. Willard Kent, Narragansett Pier, R. I.; James P. Bacon, Mrs. Bacon, Cambridge, Mass.; Mrs. A. H. Salisbury, Lawrence, Mass.; H. C. Hodgkins, Syracuse, N. Y.; A. N. Russell, Ilion, N. Y.; Daniel N. Tower, Mrs. Tower, Cohasset, Mass.; Mrs. William H. Thomas, Miss Helen A. Thomas, Hingham, Mass.; G. F. Comfort, Syracuse, N. Y.; Mrs. Fred. W. Gow, Medford, Mass.; John G. Seward, Norwich, N. Y.; Mrs. J. B. Putnam, Westboro, Mass.; J. M. Anderson, Mrs. Anderson, Worcester, Mass.; Mrs. Charles H. Baldwin, Boston, Mass.; Mrs. Louis H. Knapp, Miss Ethelind Knapp, Frank J. Illig, Buffalo, N. Y.; Charles S. Warde, Staten Island, N. Y. — 65.

Total attendance, 145.

Exhibits.

The exhibits of the Associate Members were in charge of Mr. W. H. Van Winkle, of the A. P. Smith Manufacturing Co.

The Hersey Manufacturing Co. showed a pyramid of Hersey meters of various sizes, fastened to a stand made of iron pipe. The H. Mueller

Manufacturing Co. had an exhibit comprising cocks of all kinds, tapping machines, and other appliances of their manufacture. The Thomson Meter Co. had a display of Lambert meters of various sizes. The A. P. Smith Manufacturing Co. showed their apparatus for making connections with water mains of any size up to 48-inch; a steam calking machine; a new lead kettle; and various tapping machines, sleeves, plugs, and other appliances. The Neptune Meter Co. exhibited Trident meters of various sizes. The Ross Valve Co. displayed some of its valves and other specialties. The Pittsburg Meter Co. had a good assortment of meters, in bronze and galvanized iron. The merits of the valves and hydrants made by the Eddy Valve Co. were fully set forth, as were those of the Rensselaer Manufacturing Co. The new pattern of the Walker patent fire hydrant was exhibited by the Coffin Valve Co. The Union and Columbia meters, made by the Union Water Meter Co., were displayed by that company. The Walworth Manufacturing Co. exhibited the Hall tapping machine, Walworth gate valves, and a variety of water works tools. The National Meter Co. had samples of the various brands of meters of their make. The Worthington meters were also exhibited. The Lead-Lined Iron Pipe Co. displayed samples of straight pipe, curves, branches, etc., in lead-lined and tin-lined pipe.

WEDNESDAY, SEPTEMBER 13.

The convention was called to order at 11 A.M., by President Forbes, who called upon Mr. William R. Hill to present the Mayor of the city to the Association.

Mr. Hill. *Mr. President and Gentlemen of the New England Water Works Association*, — How glad the citizens of our city are to welcome you here will be told you by a gentleman who had at one time the distinguished honor of being the youngest Mayor of any city in the United States; and if his health continues good I have no fear in saying that perhaps at some day he will have the distinguished honor of being the oldest Mayor of any city in the United States. I have the honor of introducing to you, gentlemen, our Mayor, the Honorable James K. McGuire. [Applause.]

Address of Welcome by Mayor McGuire.

Mr. Hill, Mr. President, and Gentlemen of the New England Water Works Association, — It is hardly necessary for me to say that after the exceedingly fulsome eulogy, of which I consider myself the undeserving recipient, I scarcely know what to say to you. I am very glad that I kept running for Mayor of Syracuse until I lost the title of "Boy Mayor." There was nothing that at first made me feel so

much ashamed of myself as to be introduced everywhere about the country in about the same way that a fakir would introduce a freak in a museum or a curiosity in a circus, as the "Boy Mayor." Everybody would naturally expect an exhibition by me of some peculiar boyish antics, and it was the fashion for a long time here in the city — I am glad to say we have outgrown that now — to put me in occasionally as the pitcher for the local baseball team, to select me as referee for a football match, and to ask me to do many things except serious things. But I am glad that my friend Mr. Hill acknowledges that I have been Mayor long enough to have outgrown my youthful title. Yet, after all, we are all boys only of a larger growth; and judging from some observations that I have made from the windows of the City Hall during the past twelve hours, some of the members of the New England Water Works Association are old boys and rather frisky ones. [Laughter.]

I am sure that I voice the prevailing opinion in Syracuse when I say that one and all we are profoundly grateful to you for having come to our beautiful little city. We here in the money-making and money-mad State of New York appreciate the culture and the intellect of New England, before which we all reverently bow. I know that the members of this Association in their own cities have been surfeited with speeches from the various orators who have made New England famous throughout the world. You come from a section of the country which can boast of orators of the past, such as Wendell Phillips and Daniel Webster and William Lloyd Garrison, and of speakers of the present day like Mr. Lodge and Mr. Collins and Mr. Hoar, and I presume a man would be daring indeed who would venture to mention before a New England audience the name of Edward Atkinson. [Laughter.] But the fact that you have been accustomed to sit at the feet of such distinguished orators makes us practical New York Tammany or Platt politicians hesitate about addressing you, gentlemen from New England, who are so totally unfamiliar with and so innocent of the real meaning of that hated word "practical" politics. We often notice at national conventions that the delegates from New England, especially from Massachusetts, seem to wear a most superior air. And while apparently these delegates are very independent, and come to conventions wholly uninstructed, we have noticed with what remarkable facility and how quickly gentlemen from Maine and New Hampshire and Connecticut and Massachusetts are able to get onto the band wagon and join the

winners somehow, even though they are outside of the machine. [Laughter.]

It was a very creditable action on the part of our efficient superintendent of the Syracuse Water Department to secure the holding of your present convention in this city. And I am bold enough to say that after you have observed the workings of our water department, and seen the operation of our most successful system, you will go away feeling satisfied with your visit, and knowing that you have obtained some very useful and interesting information. And I am glad to take advantage of this opportunity publicly to pay my tribute to the ability, the industry, and the energy of Mr. William R. Hill [applause]; and I can venture to assure this assemblage, speaking as a very practical politician, that whatever political party chances to be dominant in the municipal affairs of the city of Syracuse. no political party would dare, in the face of an overwhelming public sentiment, to change the superintendent of the Syracuse Water Department. [Applause.] To him and to the efforts of the Water Board, who have complete confidence in him, has been due the notable success of our water system. I think that the administration of that department is a complete answer to all the objections that have ever been made to the municipal ownership and operation of water plants. We here in Syracuse for years had been subject to exorbitant charges for water and to a very inferior system of distribution. Public sentiment became aroused to the necessity of the city owning and controlling its own water supply, and the result of the agitation and work is the possession now by the city of Syracuse of this beautiful Skaneateles Lake and of this magnificent water system of which we so proudly boast. I think that under municipal ownership the water is supplied considerably more than one half cheaper than it was under private ownership; and in addition to that, the city is abundantly supplied with pure and wholesome water. Our water works to-day stand as an object lesson for the whole United States.

Mr. Hill, as the superintendent of the water department, has also demonstrated the success of what may be termed the day-labor plan in extending the water works distributing system throughout the city. Formerly the mains were laid by the contract system, but Mr. Hill prevailed upon the Water Board to change to the day-labor system, and his report upon that subject furnishes very interesting reading. The day-labor system has often been objected to as extravagant on the ground that an unnecessarily large number of men would be

employed, and that politics would enter into the work to such a degree that it would be much more expensive than the contract system. But where we have an efficient, practical business man at the head of the department, such as we have here in Syracuse, we will be able to prove to you that the laying of pipe under the day-labor plan is more economical from the standpoint of the taxpayers and more efficient from the standpoint of good work. We invite your attention to that fact as demonstrated in Syracuse.

It would be wholly out of place for me as a layman to attempt to talk technically of the advantages of our water works to you, gentlemen, who are all hard-headed practical men. It is simply my pleasure to bid you a cordial welcome in the name of the one hundred and thirty thousand men, women, and children who make up the population of this municipality of ours. I bid you welcome in the name of all the people of Syracuse. I trust that your stay among us will be pleasant, and that when you return to New England you will carry with you the pleasantest recollections of your visit to this inland metropolis of the Empire State. I thank you very kindly for your courteous attention. [Loud applause.]

Response by President Forbes.

Mr. Mayor, — In behalf of the New England Water Works Association, I desire to thank you for your cordial welcome. I assure you that the members and guests of our Association will heartily appreciate all you may do for us while we are in your city. And I take this opportunity to extend an invitation to you and through you to the citizens of Syracuse to attend any or all of our meetings, and to take part in our discussions. I think Mr. Hill deserves great credit for the program he has laid out for our pleasure and instruction. We have heard a great deal about the thrift, the energy, and the hospitality of the people of Syracuse and of the natural beauties of your city, and we are glad to be able to see and realize for ourselves that the accounts which have reached us are not exaggerations, but plain truths. [Applause.]

ELECTION OF NEW MEMBERS.

The Secretary read the names of the following applicants for membership, they having been approved and recommended by the Executive Committee.

Resident Active.

James Burns, Water Commissioner, Lynn, Mass.

Charles E. Riley, member Water Board, Brookline, Mass.

J. H. Stubbs, Superintendent Streets and Water Works, St. Albans, Vt.

Walter H. Sears, Water Works Construction Engineer, Plymouth, Mass.

August Fels, member Water Board, Lowell, Mass.

Non-Resident Active.

Clarence W. Hubbell, Engineer Water Works, Detroit, Mich.

Frank J. Illig, Superintendent of the Water Department, Buffalo, N. Y.

A. N. Russell, President Board of Water Commissioners, Ilion, N. Y.

S. Hook, Civil Engineer, Oneida, N. Y.

On motion of Mr. Kent the Secretary was directed to cast the ballot of the Association in favor of the applicants, which he did, and they were declared by the President elected to membership.

The President then delivered his annual address, which follows.

THE PRESIDENT'S ADDRESS.

Gentlemen of the New England Water Works Association, — The Association meets to-day for its eighteenth annual convention, and for the first time in its history outside of New England. We may reasonably expect that a meeting held so far from home, and under unusual surroundings, will give new experiences and ideas to the members, and in the end result in much good to all.

Mr. Willard Kent, the President of the Association for 1898, in his annual address, very aptly alluded to the growth in numbers of our Association, to its great importance, and to the influence it is capable of exerting on all matters relating to the problem of supplying pure water to the people.

There seems to be no better subject for this brief address than the public good which our Association can do, and which it ought to do, with a few suggestions as to the way such a desirable end may be obtained. A president who has occupied the chair for one year realizes at the expiration of his office, more fully perhaps than any

other man in the Association, the amount of information this Association is capable of imparting to all those who are interested in water supply questions.

It is well to bear in mind the fact that our membership roll contains the names of nearly all the prominent men in this country and in Canada who are grappling with the great water supply problems of the day, as well as most of the superintendents from the small cities and towns of New England, and a great many from the small cities and towns outside of this area, — a large army of scientific and practical workers. The knowledge which exists, therefore, among us must be most extensive and varied, and our Association should not only give the fullest expression to the most scientific minds, but the purely practical man should receive equal consideration, and our *Journal* should print alike matters relating to theory and practice.

We all realize that we are ever moving on, and we must not for one moment consider that our knowledge to-day is sufficient for tomorrow, but is rather another step on which to mount and reach still higher. I think no one will dare to say that the limit of knowledge of water works problems is reached, especially when he carefully reviews the enormous progress made during the last quarter century; and undoubtedly the water works official who lives fifty years from this time will look back with a kind of pity upon those who managed the water systems in 1899.

Keeping, then, in mind the fact that increased knowledge will come, why should not our Association lead instead of follow? Why should not only this country, but the world turn to the publications of this Association for the latest information concerning everything relating to water works? We possess advantages for obtaining information which no weekly or monthly publication possesses, having among our members, as just stated, the men who design, and the men who have the rich experience of maintaining the things designed.

We hardly need to state that the value of a thing is not in the beauty of its design alone, but rather in its ability to stand the wear and tear of daily use. A water gate, for instance, may open and shut easily, and may be tight; but when the time comes to pack the spindle, the stuffing box may be so made that new packing cannot be inserted without cutting the gate out of service, — a serious defect, but not discovered, perhaps, until repairs were needed. This is only one of a thousand things which might be mentioned relating to the practical part of our work.

We all know that the knowledge in the world to-day is simply the sum of experience. As a graphic illustration I might state that the magnificent Atlantic liner of to-day has developed from a dug-out canoe. Experience to be of value must be recorded in such a way that it can be found when required.

Now let us look closely to the possibilities of our Association for accumulating and disseminating knowledge. As I have before stated, our Association includes nearly all of the leading specialists in this country in all branches of hydraulic subjects, as far as they relate to supplying cities and towns with water for domestic and fire purposes. These men should be induced to make our *Journal* one of the means, if not the chief means, of giving expression to their ideas and experiences. An account of all large and all important engineering works should be published with illustrations. Engine tests should not go unnoticed. Failures of all kinds should be recorded. We have a small army of men whose lives are spent in the maintenance of water works, yet we hear very little from the most of them. All should be encouraged to accustom themselves to make careful notes of their work, and present to the Association all information of value. In other words, our *Journal* should be made, and can be made, a great history of all water works subjects.

The *Journal* can also become more useful by printing, in a brief way, such parts of the annual reports of the various cities and towns as are of permanent value. The Massachusetts State Board of Health is now doing a great and good work in a study of the action of water used for domestic purposes on lead service pipes. This Board is accumulating information on this subject which is new, and which will be of great public good. Much of this information will appear in their next annual report; but comparatively few will have access to this report, and the results of these studies should be printed in our *Journal*. I cite this case as only one of many.

I do not doubt that the interests of the Association can be promoted by the employment of a permanent secretary, if the right man can be obtained, who shall give his whole time to the business of the Association, and shall also act as senior editor of the *Journal*. By such an arrangement, much useful information can be brought before the Association which would not otherwise be obtained. I hope the time is not far distant when this arrangement can be effected, but under the present rate of annual assessment the means of the Association are not sufficient to meet the additional expense.

In this connection I wish to speak of the library in the rooms of the Association in Tremont Temple Building, Boston. I should greatly favor an annual expenditure of one hundred dollars or more for the purchase of books which relate to water works matters to be added to the library. Very few of us can ever expect to have a complete library dealing wholly with hydraulic subjects, and the benefit to the members of an opportunity to consult such a library as the one at our headquarters can be made would be very great, and would be worth many times over the cost to the members. I hope that some action will be taken at this meeting favorable to the above recommendation.

I am also of the opinion that our by-laws should be revised to meet the present needs of the Association. I hope this matter can be looked upon without any prejudice, and in a strictly business manner, and that a committee will be appointed at this meeting to take this matter in hand.

The usual meetings have been held during the year. At the winter meetings a successful attempt was made to have only one subject considered at each meeting. The idea was to bring together as much information as possible on one subject at one time, and have it recorded for future use. None of the subjects introduced at the winter meetings were exhausted by any means, although the papers were numerous, and were presented by men of recognized ability.

There is one phase of our meetings which I wish to emphasize, and that is the benefit derived from the informal exchange of ideas outside of the hours of business session. I think this is the most pleasant way of obtaining information, and that it should not be disregarded by any member. Even if new ideas are not always obtained, it is a great satisfaction to know that we are at the front.

Death, who shows favors to no one, has taken from our number during the past year the following members : Lemuel Ameoman, C.E., Scranton, Pa. ; George E. Batchelder, Water Registrar, Worcester, Mass. ; David B. Kempton, Chairman Water Board, New Bedford, Mass. : Charles F. Murphy, Inspector, Marlboro, Mass. ; Edward C. Nichols, Water Commissioner, Reading, Mass. ; Charles H. Swan, C.E., Boston, Mass.

The report of the Treasurer and Secretary, immediately following this address, will give the necessary information relating to the finances and membership of the Association.

In conclusion, I wish to thank all of those who have so generously

contributed papers, and have coöperated in other ways to make the meetings of the past year of permanent value to those interested in water works problems — some of the most vital problems of the age.

I hope the future will show even increased activity, and that all will strive to add something to the world's great storehouse of wisdom.

REPORT OF FINANCE COMMITTEE.

Mr. W. F. Codd, for the Finance Committee, reported that the Committee had examined the accounts of the late George E. Batchelder, as Treasurer of the Association, and found them correct. The Committee submitted the following report, which was accepted and placed on file.

REPORT OF THE TREASURER, GEORGE E. BATCHELDER, IN ACCOUNT WITH THE NEW ENGLAND WATER WORKS ASSOCIATION.

RECEIPTS.

1898.			
	Balance on hand as per last report:		
	City National Bank	$ 346.41	
	People's Savings Bank	1,161.04	
	Safe Deposit & Trust Co.	1,429.47	
			$2,936.92
October 20.	Received from J. C. Whitney, Secretary	$600.00	
December 16.	,, ,, ,, ,, ,,	150.00	
,, 31.	,, ,, ,, ,, ,,	200.00	
1899.			
January 11.	,, ,, ,, ,, ,,	100.00	
,, 26.	,, ,, ,, ,, ,,	350.00	
			$1,400.00
February 1.	People's Savings Bank, interest	$ 22.99	
July 1.	City National Bank, ,,	1.92	
,, 1.	Safe Deposit & Trust Co. ,,	37.54	
			$ 62.45
			$4,399.37
July 1.	Bills paid by J. C. Whitney, Secretary		563.26
			$4,962.63

EXPENDITURES.

1898.			
July 15.	Boston Society of Civil Engineers	$50.00	
September 1.	W. H. Richards	77.00	
,, 29.	Electro Light-Engraving Co.	7.30	
,, 30.	Bacon & Burpee	65.00	

October 10.	J. C. Whitney	$125.00	
,, 10.	,, ,,	122.08	
,, 13.	Electro Light-Engraving Co.	8.55	
,, 14.	,, ,, ,, ,,	2.50	
,, 24.	Newton Journal	38.85	
,, 27.	W. T. Almy	13.20	
November 1.	Day Publishing Co.	250.04	
,, 5.	Fanning Printing Co.	45.00	
December 1.	W. H. Richards	81.95	
,, 1.	J. C. Whitney	125.00	
,, 1.	,, ,,	35.20	
,, 15.	Electro Light-Engraving Co.	12.58	
October 1.	Frank A. Andrews	10.18	
,, 15.	Boston Society of Civil Engineers	100.00	
December 10.	Newton Journal	6.00	
,, 31.	Henry F. Jenks	25.00	
1899.			
January 11.	Beethoven Quartette	25.00	
,, 12.	Day Publishing Co.	182.16	
,, 13.	Thomas P. Taylor	10.00	
			$1,417.59

PAID BY J. C. WHITNEY, SECRETARY.

February 2.	Electro Light-Engraving Co.	$ 16.95	
March 8.	Francis L. Pratt	30.00	
,, 9.	Thomas P. Taylor	20.00	
,, 13.	W. H. Richards	107.43	
,, 22.	Boston Society of Civil Engineers	100.00	
,, 24.	Electro Light-Engraving Co.	30.15	
,, 28.	Day Publishing Co.	230.79	
,, 31.	Newton Journal	9.94	
April 1.	H. F. A. Lange	10.00	
,, 16.	R. H. Woodhouse	8.00	
			$ 563.26
			$1,980.85
	Error in payment		8.00

BALANCE ON HAND.

July 1.	Transferred to Worcester National Bank	$1,467.01	
,, 1.	City National Bank	322.74	
,, 1.	People's Savings Bank	1,184.03	
			$2,973.78
			$4,962.63

Respectfully submitted,

A. W. F. BROWN,
WM. F. CODD,
HORACE KINGMAN, } *Finance Committee.*

August 2, 1899.

REPORT OF TREASURER BANCROFT.

Mr. Lewis M. Bancroft, who was elected Treasurer in place of Mr. Batchelder, deceased, read the following report, which was accepted and placed on file.

LEWIS M. BANCROFT, TREASURER.

In account with New England Water Works Association.

RECEIPTS.

1899.			
August 2.	Received from Finance Committee:		
	Deposit People's Savings Bank	$1,184.03	
	,, Worcester National Bank	1,467.01	
	,, City National Bank	322.74	
		$2,973.78	
September 2.	Received from J. C. Whitney, Secretary	800.00	

EXPENDITURES.

August 30.	W. H. Richards, salary to June 1, 1899, postage, telegrams, etc.		$ 82.38
	C. A. W. Spencer, printing tables		13.00
	Bacon & Burpee, report of winter meeting		76.75
	Newton Journal, printing envelopes, bills, etc.		15.45
	Electro Light-Engraving Co., engraving plates		38.45
September 4.	C. H. Curtis, caterer		62.50
	Lynn & Boston Railroad, car fares June meeting		18.00
	Boston Society Civil Engineers, rent to June 1, 1899		150.00
,, 5.	Samuel Hobbs & Co., envelopes, letter-book, and Journal		4.40
	W. N. Hughes, envelopes and printing		2.25
	J. M. Ham, salary February 15 to August 18, 1899, postage and express		162.16
	The Day Publishing Co., printing June Journal		436.04
			$1,061.38

BALANCE ON HAND.

People's Savings Bank	$1,184.03		
Worcester National Bank	1,467.01		
City National Bank	9.56		
First National Bank, Reading	51.80		
			2,712.40
		$3,773.78	$3,773.78

LEWIS M. BANCROFT.

REPORT OF THE SECRETARY.

The Secretary submitted the following report, which was received and placed on file.

Summary of Statistics relating to Membership for Year ending June 1, 1899.

ACTIVE MEMBERS.

June 1, 1898.	Total active membership		488	
	Withdrawals during year		15	
			473	
	Initiations.			
	September, 1898	7		
	December, 1898	4		
	January, 1899	3		
	February, 1899	2		
	March, 1899	5		
			21	494

HONORARY MEMBERS.

June 1, 1898.	Honorary members	5	
„ 1, 1899.	„ „		5

ASSOCIATE MEMBERS.

June 1, 1898.	Total associate membership	77	
	Withdrawals during year	5	
		72	
	Initiation, February, 1899	1	
			73
June 1, 1899.	Total membership		572

Mr. W. R. Hill, Superintendent and Engineer, Syracuse, N. Y., then addressed the convention, explaining his method of removing vegetable organisms from the water in the distributing reservoir of the city of Syracuse. The paper was discussed by Messrs. Haskell, Fish, Hazen, Hodgkins, Forbes, and the author.

During the afternoon a visit was made to the Syracuse distributing reservoir and an exhibition by the fire department was witnessed.

EVENING SESSION.

At the evening session Allen Hazen, C.E., of New York City, gave an informal talk, illustrated with lantern slides, describing the new filter plant at Albany, N. Y.

Prof. E. A. Fuertes, Director of the College of Civil Engineering, Ithaca, N. Y., described the new hydraulic laboratory of the College of Civil Engineering, Cornell University, illustrating his description by lantern slides.

A paper descriptive of the Flood Water Channel of the Altoona, Pa., Reservoirs, by Charles W. Knight, C.E., of the Stanwix Engineering Co., Rome, N. Y., was read by Charles C. Hopkins. This was also illustrated by the stereopticon.

THURSDAY, SEPTEMBER 14.

At 9 A.M. the members and guests took a special train to Lake Skaneateles, the source of the Syracuse Water Supply. After viewing the dam and gate house at the outlet of the lake, the party proceeded by steamer to Glen Haven, at the upper end of the lake. Lunch was served there; and the return to Syracuse was made at 6 P.M.

In the evening there was a banquet at the Yates Hotel, at which speeches were made by Mr. W. R. Hill, Mr. T. E. Dwyer, Mr. Wiles, and others.

FRIDAY, SEPTEMBER 15.

In the absence of President Forbes, Vice-President Byron I. Cook called the meeting to order and announced that the first business was the election of officers.

Mr. Willard Kent in behalf of the Nominating Committee submitted a report, which was read by the Secretary, as follows: —

ASSOCIATION HEADQUARTERS, BOSTON, MASS., June 1, 1899.

The Nominating Committee submit the following list as officers of the New England Water Works Association for the ensuing year: —

President.

BYRON I. COOK, Superintendent, Woonsocket, R. I.

Vice-Presidents.

C. K. WALKER, Superintendent, Manchester, N. H.
M. A. SINCLAIR, Superintendent, Bangor, Me.
R. S. BARTLETT, Superintendent, Norwich, Conn.
W. E. HAWKS, President, Bennington, Vt.
F. E. MERRILL, Superintendent, Somerville, Mass.
T. G. HAZARD, Jr., Civil Engineer, Narragansett Pier, R. I.

Executive Committee.

P. KIERAN, Superintendent, Fall River, Mass.
J. C. HASKELL, Superintendent, Lynn, Mass.
R. J. THOMAS, Superintendent, Lowell, Mass.

Secretary.

WILLARD KENT, Manager, Narragansett Pier, R. I.

Treasurer.

L. M. BANCROFT, Superintendent, Reading, Mass.

Senior Editor.

J. E. BEALS, Superintendent, Middleboro, Mass.

Junior Editor.

C. W. SHERMAN, Asst. Supt. Metropolitan Water Works, Cambridge, Mass.

Finance Committee.

A. W. F. BROWN, Registrar, Fitchburg, Mass.
W. F. CODD, Superintendent, Nantucket, Mass.
J. W. CRAWFORD, Secretary, Lowell, Mass.

Respectfully submitted,

WILLARD KENT,
JOHN C. HASKELL.
GEORGE A. STACY,
DEXTER BRACKETT,
HORACE G. HOLDEN,
Committee.

The report of the committee was accepted and adopted, and the Secretary was instructed to cast the ballot of the Association in favor of the nominees, which he did, and they were declared elected.

President-elect Cook, after briefly thanking the Association for the honor conferred upon him, and expressing the hope that he might be able to conduct the affairs of the Association in as satisfactory a manner as had been done in the past, read a paper on "Standpipes." The paper was discussed by Messrs. Haskell, Bassett, Hawley, Beals, and Bancroft.

Prof. Gardner S. Williams, Engineer in charge of the Hydraulic Laboratory, Cornell University, next read a paper entitled "Some

Notes on the Design of Water Works Distribution Systems." Messrs. Kuichling, McKenzie, Hazen, Walker, Fish, and Haskell participated in the discussion of the paper.

George I. Bailey, Superintendent, Albany, N. Y., next read a paper entitled "The Care of Fire Hydrants in Winter."

AFTERNOON SESSION.

At the afternoon session Vice-President Walker occupied the chair.

F. H. Crandall, C.E., Superintendent and Treasurer, Burlington, Vt., read a paper entitled "Methods of Assessment and Collection of Water Rates." The discussion which followed the reading of the paper was participated in by Messrs. Walker, Kuichling, Sullivan, McKenzie, Hawley, Whitney, Hazen, Russell, and Bancroft.

Louis H. Knapp, Engineer of the water works at Buffalo, N. Y., read a paper descriptive of those works.

CLOSING EXERCISES.

VICE-PRESIDENT WALKER. I want to say it was a long distance for an old man to come, but I am glad I came. I can think of no place where we have ever met where we have enjoyed ourselves more than we have here, and I for one want to thank the people of Syracuse for asking us to come, and for the entertainment they have given us. I never expect to come here again to a water works convention, but I can recommend Syracuse wherever I go. [Applause.]

MR. WHITNEY. Before we adjourn I think it is fitting that we should put on record some slight testimonial of our appreciation of our visit to Syracuse, and also of the reception we had in the city of Albany. That we do appreciate everything that has been done for us I think our friends in Syracuse and in Albany fully believe, but I think you will all agree with me that it is well to put upon our records the following resolutions: —

Resolved, That the thanks of the members and guests of the New England Water Works Association be extended to Mr. William R. Hill, to the Syracuse Water Board, to the Reception Committee, and to the citizens of the city of Syracuse for the cordial welcome, the untiring interest, and

the lavish entertainment that they have given us, and that have so largely contributed to the notable success of this convention.

Resolved, That the thanks of the New England Water Works Association be extended to the Water Board of the city of Albany, its Superintendent and Engineer, for courtesies extended on our recent visit to the filter plant of their city.

Mr. Haskell. I would like to make the suggestion that the Secretary be authorized to send a copy of these resolutions to the various parties mentioned.

Mr. Stacy. I will move the adoption of these resolutions, that a copy be sent to the various parties mentioned in them, and that they be spread upon our records in indelible ink, and we will not forget that Mrs. Hill is included. [Applause.]

The motion was seconded by many members and adopted by a rising vote.

On motion of Mr. Stacy, there being no further business to come before it, the convention adjourned.

PRESENTATION TO MR. AND MRS. HILL.

A pleasant feature attending the closing exercises of the convention was the presentation to Mr. and Mrs. Hill of a beautiful cabinet, the gift of visiting members of the Association. A large number of them accompanied by the ladies having assembled in the convention hall, Mr. Haskell called to order and said: —

Ladies and Gentlemen in general, and Mr. Hill and Mrs. Hill in particular, — It is with heartfelt pleasure that I now present to Mr. Hill and his wife this cabinet [applause], representing as it does a slight expression of the gratitude felt by the members of the New England Water Works Association, who have been so generously entertained during this convention as the result of the efforts of Mr. Hill and his wife, assisted by the citizens of Syracuse. [Prolonged applause.]

Mr. Hill responded as follows: —

Mr. Haskell, Ladies and Gentlemen, — I am unable to thank you in a fitting manner for this very beautiful gift, but I assure you that there is already engraved upon my memory a recollection that I hope will exist for many years, of the high honor which you have paid our

city in making us this visit. While perhaps in future years memory may fade, I am pleased to have this beautiful gift which shall always remain with us and be handed down to our children to be a perpetual reminder of your kind generosity. [Loud applause.]

Mrs. Hill. I wish to say that I thank you all. [Enthusiastic applause.]

OBITUARY NOTES.

Charles F. Murphy, Inspector for the Water Department of Marlborough, Mass., was drowned on April 6, 1899, while crossing the ice on Fort Meadow Pond.

James W. Morse, Superintendent of Water Works, Natick, Mass., died on September 23, 1899, aged 68 years. He leaves a wife and three daughters.

Mr. Morse was a member of the committee which constructed the Natick water works, and upon their completion he was made superintendent, and he had held this office continuously, with the exception of one year, for about twenty-five years.

Henry W. Conant, Superintendent, Gardner, Mass., died November 18, 1899, of apoplexy.

Horace B. Winship, Civil Engineer, of Norwich, Conn., died in that city on November 8, 1899.

PRESIDENTS

OF THE

New England Water Works Association.

James W. Lyon, 1882–83.

Frank E. Hall, 1883–84.

George A. Ellis, 1884–85.

Robert C. P. Coggeshall, 1885–86.

Henry W. Rogers, 1886–87.

Edwin Darling, 1887–88.

Hiram Nevons, 1888–89.

Dexter Brackett, 1889–90.

Albert F. Noyes, 1890–91.

Horace G. Holden, 1891–92.

George F. Chace, 1892–93.

George E. Batchelder, 1893–94.

George A. Stacy, 1894–95.

Desmond Fitzgerald, 1895–96.

John C. Haskell, 1896–97.

Willard Kent, 1897–98.

Fayette F. Forbes, 1898–99.

Byron I. Cook, 1899——

Plate I.

Cornell University Campus and Cayuga Lake.

(Frontispiece.)

NEW ENGLAND WATER WORKS ASSOCIATION.

ORGANIZED 1882.

Vol. XIV March, 1900. No. 3.

This Association, as a body, is not responsible for the statements or opinions of any of its members.

THE HYDRAULIC LABORATORY OF CORNELL UNIVERSITY.

BY PROFESSOR E. A. FUERTES.

[*Read September 13, 1899.*]

Gentlemen, — I appear before you at the request of your worthy President. Lack of time made me doubt that I could prepare a paper of sufficient importance for the purposes of this Association; but the nature of your work, as well as the opportunity afforded by this meeting of hydraulicians, forced me to make the effort to bring to you at least a message from the hydraulic laboratory of Cornell University, even though this paper is the result of a hasty and almost uncorrected dictation.

My only object is to give a brief history of the great laboratory built by Cornell University for the purpose of advancing the progress of hydraulic science, and to invite any and all of you to make use of its possibilities for research. To secure this object, means have been and will be provided to carry on hydraulic investigations with a large plant and on a suitable scale.

It is needless to say before this body of expert hydraulicians that the day is past for what have been known hitherto as class-room experiments in hydraulics. No important designs can be wholly based upon the results of such experiments. We all have found, and not in a few or unimportant cases, that it is not safe to use the results of experiments made on a small scale, or if the experiments do not reach the conditions which exist in actual practice. Modern practice is becoming daily more exacting, since the magnitude of our undertakings demands the solution of new and larger problems.

However interesting and necessary the labors of early experimenters may have been in this field, the improvements effected by them have served to demonstrate that the experiments upon which new theories of hydraulics have been based can be considered only as steps in the rational evolution of this difficult science. The purposes of the Cornell laboratory are to pass beyond tentative and disproportionate experimentation into the field of actual research under the natural conditions which the engineer actually meets in his professional life.

The evolution of this laboratory has been slow. When I was called to the Deanship of what was then the Engineering Department of Cornell University, I had three general ideals in view: first, to endeavor to raise the social standing of the engineering profession, the economic value of which is still very much misunderstood and underrated; second, to improve the professional preparation required for the discharge of the important functions of the engineer as the creator of industrial wealth in a country radically different in every respect from older European communities; and, third, as a corollary to these differences of conditions, to establish a rational system of laboratory work that would avoid tendencies toward empiricism, by making this work go hand in hand with the theory of the class rooms.

Since even the blind experimental labors of the alchemist made possible the discoveries which have converted empirical chemistry into a purely mathematical science, it seemed to me that no insurmountable difficulty could be found in teaching by experimental illustrations the relations between force and matter from the engineer's point of view. I find among some old notes, that I made this statement in a lecture upon the spectroscope delivered in 1865 before a club, at Stamford, Conn.

In 1873 some experimental apparatus was constructed for the use of the students in our engineering classes. There was no intention of making any new discoveries. Experimental work on cements and on losses of head through elbows and through sudden changes in the dimensions of pipes gave encouraging results, even though the latter were simply repetitions of work done by Weisbach, Darcy, Poncelet, Polonceau, and others. The object was to ascertain if this radical change of teaching methods could be made to become a teaching necessity. If it should prove to be effective, either by shortening the time required for instruction or by making more

thorough the results of text-book study, and if it could be introduced and perfected within reasonable limits of expense, then the realization of the full advantages of the method would be only a matter of effort and time.

The first difficulty met was our inability to obtain adequate apparatus, which in turn demanded that I should convince the authorities of the university of the expediency of attaching to the college force, permanently, a corps of skilled mechanicians. This was a step without precedent up to that time. It took ten years of missionary effort to prove that this new method was feasible and effective; but in 1880 our trustees became convinced of the advantages of this new departure in the methods of teaching engineering. I was sent to Europe to visit engineering schools and study what had been done there in this regard. I found that a considerable number of models and other material for illustrations were employed in the lower schools where geography and geometry especially, were largely taught by models somewhat in a kindergarten fashion.

In the *École des Arts et Métiers* considerable progress had been made in the application of object lessons to the arts of handicrafts; but only the famous Olivier models in descriptive geometry illustrated the actual school practice of applying models to the elucidation of intricate mental conceptions. Laboratory work for engineering students, as we now understand it, was found nowhere in Europe. On the contrary, it was frowned down as unworthy of a place in the curriculum of engineering schools. I remember well the look of supercilious disgust on the face of M. Guillemain, then the director of the *École des Ponts et Chaussées*, when I showed him photographs of some of our laboratories. He told me, "You are making mechanics, not engineers, in American schools. Go to our museums and you will see what *engineers* have planned. The artisans who made the structures you find there are not engineers — they are mechanics, trained elsewhere, and have nothing in common with us." In a few instances laboratories for the testing of materials were conducted in Europe in connection with government work, but under methods that would not prove satisfactory under the usual policies of American schools.

Laboratory work, which was also opposed by many American schools of engineering for a considerable time, has now become an ordinary and well-accepted method of teaching civil engineering all over the land; and even in France, we find to-day that M. Debray

is the professor and chief of the laboratories of the *École National des Ponts et Chaussées.* However, the important work done by this laboratory recognizes a well-marked ranking difference between the permanent trained assistant, who is a machine obeying orders, and the director of the experiments, who does no manual work himself; and nowhere in Europe are these laboratories in regular and constant use by engineering students. At most, students or graduates are sometimes witnesses of some of the government experiments.

As the result of studies abroad and what we had already accomplished at home, in June, 1884, I made a requisition upon our trustees for the beginning of a hydraulic laboratory estimated to cost about eleven thousand dollars. Considerable progress was made towards obtaining a respectable amount of useful equipment; but it was not until quite recently that it became possible to bring before our trustees such a long list of unanswered hydraulic questions, of an importance so manifest that they took an active interest in this matter and appropriated a large amount of money to be devoted exclusively to hydraulic research.

It is simple justice to state, for the encouragement of other institutions of learning, that this act of the trustees of my university will be hereafter considered as one of the most important landmarks in the history of advanced education in America. If such liberality and foresight have had no precedent in this or any other country, the example set by the existence of this hydraulic laboratory will prove to be the entering wedge that may lead the rich men of our generous land to find worthy uses for their wealth. There are indeed numberless engineering questions of great importance to mankind that will progress slowly, if at all, unless our men of wealth should become wise enough to build monuments like this laboratory for the admiration and improvement of posterity. These acts of generosity on the part of wealthy citizens are yearly growing more numerous, for our rich men understand that through these proofs of philanthropy their names are ennobled and their memories perpetuated in the manner which is freest from the accusation of "vanity beyond the grave." There is and can be no other feeling than gratitude and reverence towards such men as Harvard, Yale, Cornell, Sage, Carnegie, and a host of similar benefactors of the human race.

It also seems probable that the foundation of such means of research in our universities must be laid by the rich men of our country; for it is not likely that our government will undertake, as it

should, the task of directly fostering advanced education. Aside from the two military schools which the government supports most inadequately, and the magnificent land grants which Lincoln gave to the States in the darkest days of our Civil War, the government of the United States has done nothing for the advancement of the education of its leaders among the people. The proceeds of the land grants have been, with one or two exceptions, frittered away without adequate benefits resulting; and the government has left the important function of training our leaders to the several States, which, so far, have only cared for the threatened safety of our public schools. The signal progress made in this country in the higher branches of education is almost entirely due to private benefaction. The government of France spends yearly not far from fifty millions of dollars in its industrial and technical schools. The German government spends over two hundred thousand dollars for every million and a half of the inhabitants of its city populations. Switzerland maintains at great expense a large technical school, and in addition, cantonal and municipal appropriations, contributed cheerfully, increase the efficiency of these schools.

I am aware of the existence of schools in Europe that are believed to have splendid equipments; for instance, the one at Potsdam, near Berlin, has often been cited as an example; but so far as I have learned, after diligent study and search on the spot, these schools, even to-day, contain material and equipment used largely to increase the personal reputation of the professors. The students have little to do with the use of the equipment, for learning purposes, excepting, perhaps, in the mere handicraft and use of tools in the mechanical and artisan schools.

With us, our two national schools are very inadequately equipped, and their requirements for admission and instruction are far inferior to those of a very large number of private schools. While it is true that the government supports at Washington a considerable number of eminent investigators in scientific bureaus, these bureaus do no direct teaching, and many persons doubt that the results obtained are commensurate with their cost. This is no doubt due to their imperfect and unco-related organizations, as well as to the evil influences of bureaucracy and political corruption.

In this country private and individual philanthropy have invested at least three hundred millions of dollars for purposes which may be classified as aids to higher education. One of the most recent impor-

tant events in this direction is the creation of the Cornell University Hydraulic Laboratory, which could not be duplicated at any existing school without an expenditure of at least three million dollars; and it is still far from reaching its anticipated usefulness. In fact, it is as yet only an engine of huge possibilities, needing the wealth of working plant which can only come with time and with its own experience.

This laboratory is situated on Fall Creek, which flows along the northern limit of the university lands through a deep ravine, in a westerly direction, and finally discharges its waters into Cayuga Lake.

Plate I represents the university campus, and shows its relation to the lake, which is about four hundred feet lower in elevation. Fall Creek gorge is directly behind the farthest buildings, and the laboratory is within the woods on the extreme right of the picture. At this point the ravine suddenly broadens out and flattens upstream.

The watershed of Fall Creek is at present under survey and improvement for storage purposes. It includes an area of about 120 square miles and has a mean annual rainfall of something less than forty inches. The stream receives numerous tributaries from a variety of minor watersheds, which differ considerably from one another as to longitudinal grades, transverse slopes, and nature of the soil. A very accurate survey for hydrological purposes is being made of all these conditions, including the study of the resulting complications of the rainfall and flow over the various watersheds. Suitable weirs and other apparatus are being placed upon this area with apparatus for making automatic records at the central office of the laboratory.

A dam, curving upstream, has been thrown across the gorge to raise and collect the waters into a pool for storage purposes. The dam is made of concrete, arched in plan, but its section was designed as a gravity section. It is 156 feet long, and north of it the rock has been stripped and blasted so as to form a suitable spillway, capable of passing any possible flood without injury to the dam or to the experimental canal. The dam is at present thirty feet high and is a foot higher than the spillway. The experimental canal is sixteen eet wide and about four hundred feet long, with a depth of water of about ten feet. The water can be let into it with a head of twenty feet. The canal extends upstream for a distance of about two hundred feet above the dam. It is differentiated from the pool above by its lateral walls, provided at the upper extremity with six gates. It is intended in the future to extend the canal several hundred feet

FIG. 1. — TRIPHAMMER FALLS.

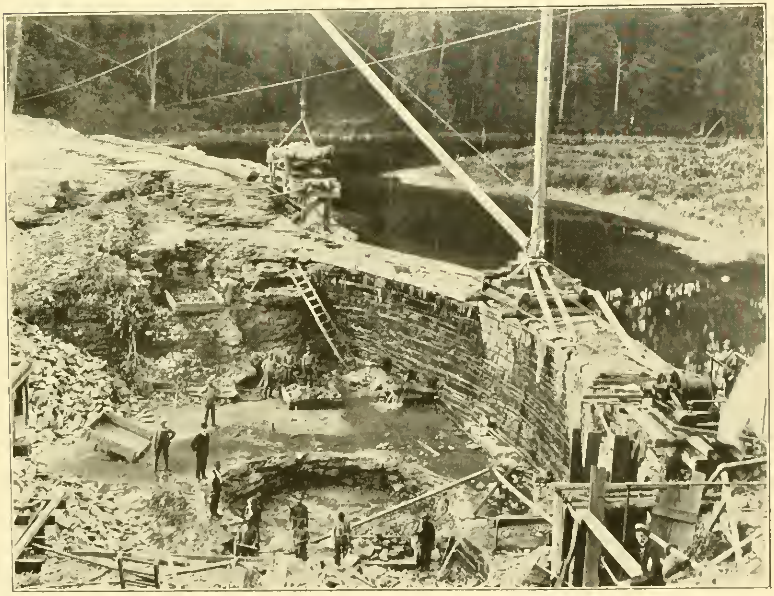


FIG. 2. — OLD DAM.

Fig. 1. — New Dam and Spillway.

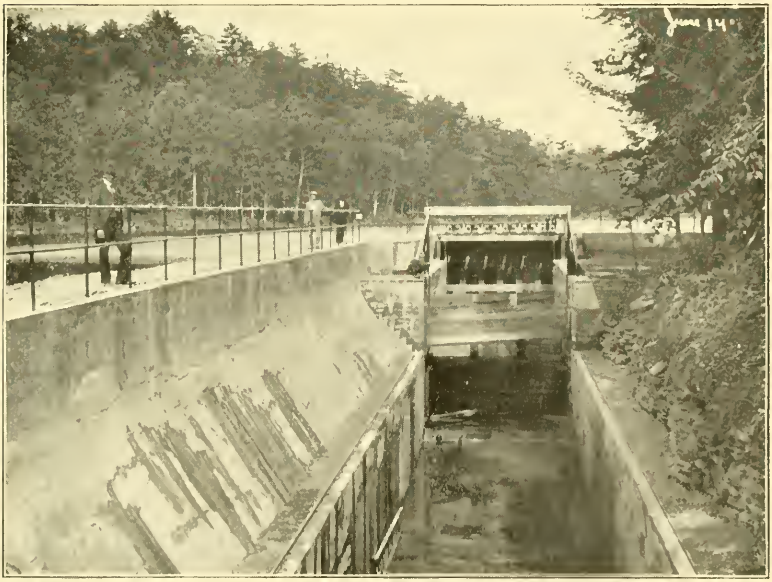


Fig. 2. — Head Gates, Experimental Canal.

farther upstream within the lower end of the pond, and also to raise the dam ten feet. The water rights which previously limited the height of the dam have been recently purchased by the university, and an increase of ten feet upon the upper pool will give more than treble the present capacity of the impounded water, making a total of about 150,000,000 cubic feet. The immense expense attending the works already accomplished made it desirable to fix upon the present dimensions of the dam; but provision has been made for the enlargement of the works as above indicated at a minimum expense, or, rather, with only the expense due to the actual additions to the laboratory.

Plate II, Fig. 1, represents the Fall Creek gorge as it was before any work was done upon the hydraulic laboratory. In the foreground is the waterfall of about thirty-five or forty feet, known as Triphammer Falls, and directly above is seen the pump house which supplied the water to the campus. Above this is the old dam, which has now been removed. The woods directly back of the dam are upon an island; the woods were burned and the island itself removed.

Plate II, Fig. 2, represents the old dam. Back of it is the island and directly in front is the beginning of the excavation for the foundation of the new dam. The dam was built in benches in front, which retreated upstream, forming steps. The back of the dam is vertical. Like the old dam, it is built as an arch, but it is designed as a gravity section dam.

Plate III, Fig. 1, shows the completed dam from the north end. The spillway is in the foreground, and the experimental canal is at the other end of the dam. The pipe seen issuing from the dam beyond the spillway is the 48-inch main, which is provided with a 24-inch gate for waste purposes. This main supplies power downstream for the shops of the university. It is proposed to extend the wall of the canal, which is four feet higher than the dam and extends about 200 feet into the pond, for some 1,200 feet.

Plate III, Fig. 2, represents the upper or east end of the canal finished, with the head gates. The gates, of which there are six, move up and down with a rack and pinion, but the gate on the extreme right moves by a wheel and worm, to be provided with verniers, so as to regulate with great accuracy the flow from the gates. Upon the walls of the canal itself are rails which will carry a truck of special construction, moved by a suitable motor, and provided with chronographs and a variety of other devices to measure velocities, depths, etc.

Plate IV, Fig. 1, shows the canal finished, looking west or downstream, and gives an idea of the relative size of the canal.

Plate IV, Fig. 2, shows the 6-foot standpipe completed, with a fixed stairway and hand rail attached to it. About halfway down are seen several connections for experiments upon pipes of various sizes and heads. Also at the bottom of this pipe is a 36-inch connection, to which can be attached piping horizontally for about 1,500 feet, with gentle vertical and horizontal curves, until it reaches the level of the lake about 400 feet below the top of this pipe. This figure also shows one of the laboratory buildings built at the foot of the cliff, whose roof is pierced by the standpipe. This is not finished, and it is intended now to continue the walls upwards, not only to prevent the marring of the wild beauty of the scenery of this place, but to enable us to make jet and other experiments with quiescent air within the walls.

Plate V, Fig. 1, shows the lower end of the canal, the standpipe, and the Triphammer Falls, with a flood discharge.

Plate V, Fig. 2, shows the appearance of the canal throughout its length and lower end in February, 1899. The accumulation of ice during that winter was considerably larger than previously observed, and the stability of the work may be inferred from the fact that after the melting of the ice no apparent damage was discovered. Of course, much of the ice seen on the right-hand side will be in the future completely obliterated by cutting off the rock seepage and draining the ground at a suitable place.

The following is a tentative program of the studies that it is intended to carry on in connection with this laboratory: —

1. Studies upon the dragging and suspending power of running water at various stages of its saturation with sediment, and of the conditions which affect these two distinct actions of water in motion.

2. The effect of transverse, longitudinal, and submerged dams and weirs, under standard conditions, and under conditions modified at will by disturbing influences, covering many varieties of complications.

3. Study upon the corrections to be made in the beds of streams to give them the most suitable and stable longitudinal profile.

4. Study upon the mechanics of such rivers as build their minor beds higher than the bottom level of their major bed. In this connection Major Leach's recent paper on "What the Mississippi is and what it needs" opens a promising field for investigation.

Fig. 1. — Experimental Canal.

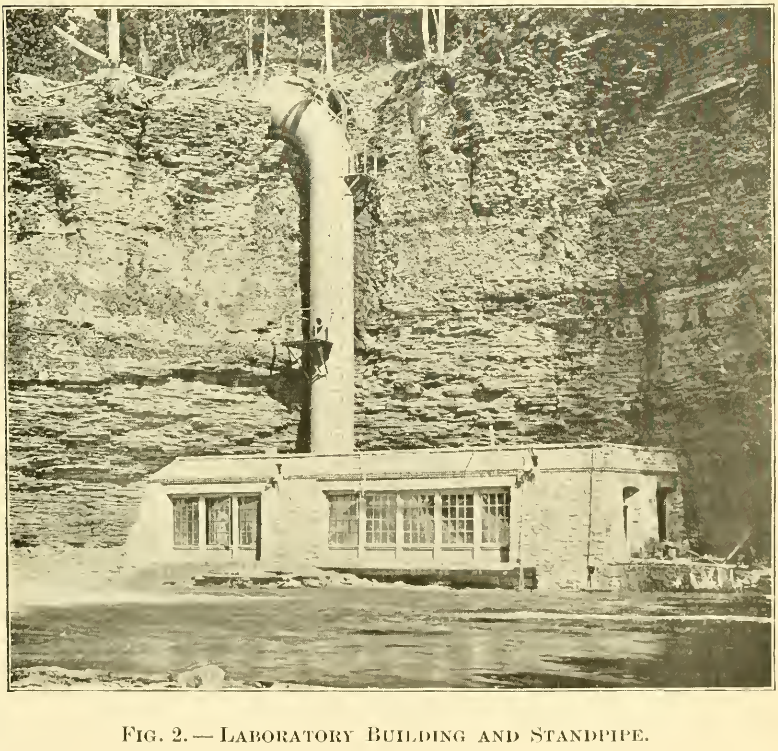


Fig. 2. — Laboratory Building and Standpipe.

Fig. 1. — Dam and Canal passing a Flood.

Fig. 2. — The Hydraulic Laboratory in Winter.

5. Study of "Littoral Cordon Formation," and of channels, bars, and deltas, and of the deposition of sediment from rivers entering into quiescent waters, and also against high tides.

6. Study of the conditions affecting the length of the straight portions, and the degree of curvature of the bends of natural and artificial water courses, looking to securing permanence of channels and of depths of water, and problems relating to slack water navigation.

7. Study upon the delivery and conditions of the watershed of the stream and its tributaries which feed this canal, with reference to the amount and kinds of suspended matter carried by floods, the interrelations of the floods of the tributary watersheds, and such studies as may prove useful for determining the coefficients of flood volume. proper lengths of dams and spillways, and height of floods over them, so as to perfect the formulæ for the delivery of watersheds, if this be possible. The watershed of this stream covers about one hundred and twenty square miles of surface, which will be most carefully surveyed topographically, geologically, and hydrologically.

8. Experiments upon the rating of current meters; the motion of water in open channels, in pipes, under ice, and over weirs; and under variable conditions of velocity, size and material of conduits, condition of surfaces, contractions, and grades. Studies on harbors and the defensive works of exposed coasts.

9. Determination of the resistance to the motion of boats in canals in reference to their respective cross sections; limits of speed, effect of waves, etc.

10. Experiments on water jets, which embrace a broad field for new work upon the forms of water-wheel buckets, fire protection, ratios of areas and forms of propellers, including water jet scouring and propulsion.

11. Experiments on the tests, design, construction, and efficiency of water and other motors, including water meters and tachometers.

12. Effects of the form and conditions of the surface of vessels upon their speed, motive power required, and ratios of velocities and resistances.

The few investigations already made at this laboratory upon the single subject of weirs have opened many new fields for research, which seem to promise new and simpler scientific solutions for these important kinds of measurements.

The uses of this laboratory are not restricted simply to the study of hydraulic questions. For example, on the sanitary side, the relations that should exist between the grade of a sewer, its size, and the volume of flushing water required to produce a given effect, are almost entirely unknown. The work of S. H. Adams, recently published, does not supply the needs of hydraulicians with the required generality that the equipment of this laboratory may furnish.

Many additional investigations in reference to sanitary engineering are being studied, but to detail them seems unnecessary at present. They bear upon a better scientific foundation for engineering biology, upon the preservation of standards of purity in water supplies, and upon proofs to be furnished in order to improve the personnel and widen the powers of our Boards of Health, whose labors, with very few exceptions, have proved most disappointing throughout the entire country; in fact, this laboratory may be made to contribute to the development of the science of "Public Medicine," which is as yet an unoccupied field urgently demanding its rights as a social factor of great importance. Also, this laboratory can count upon the aid and use of the large resources of the physical, chemical, and biological laboratories of the university with their personnel, libraries, and equipment.

The Hydraulic Laboratory has recently been engaged in some experiments for the United States Deep Water-Ways Commission, mainly upon the determination of coefficients to be employed for the delivery of water over weirs. It is to be regretted that they were restricted to a repetition of Bazin's experiments, although they were carried on beyond the heads employed by that distinguished experimenter.

Several new questions to be studied, as soon as they can be reached, have been brought out from various parts of the world, and it is to be hoped that members of this Association will refer to this laboratory any questions the solutions of which may be desired. In fact, this laboratory is entirely at the disposal of hydraulicians in this or any other country. Questions may be referred to it for solution either by us or by their visiting engineers, who will be welcome to use the facilities of this laboratory to their full extent, and perform any experiments they may desire. The only restriction that it seems fair to impose is that important experiments under way for the time being may not be disturbed by new questions, or that we

may not be required to go to great expense, for it seems proper, in these cases, that the parties interested should bear their share of the expense; but in all questions of public or general utility, this laboratory intends to be generous with its personnel, resources, time, and equipment.

The plans of this laboratory after they left my hands were placed in charge of Frank S. Washburn, C.E., of New York City, a graduate and trustee of Cornell University. The work of construction was under the direction of another graduate of the University, Dr. Elon H. Hooker, C.E., now Deputy Superintendent of Public Works of New York State.

In July, 1898, the laboratory, in so far as it was then completed, was formally transferred to my care as part of the equipment of the College of Civil Engineering of Cornell University. Gardner S. Williams, late civil engineer to the Board of Water Commissioners of Detroit, was elected by the trustees as professor of experimental hydraulics, and is the engineer directly in charge of this laboratory and responsible for its work.

Permit me, Mr. President, to repeat again the message I bring to this Association. If at present, or in the course of the practice of its members, there should arise any questions that might be determined, improved, or advanced by experimentation, I feel justified, in the name of the authorities of Cornell University, to extend to you a truly cordial invitation to use this laboratory and avail yourselves of whatever advantages it may offer for these purposes, which are the only ones for which it exists.

I may include with this invitation the statement that the college staff, among whom there are distinguished hydraulicians and engineers, will always be glad to aid any efforts to advance the progress of hydraulic science; and Professor Williams, the engineer in charge, you will find always ready to coöperate with any one as to the arrangements and details of the work under his immediate care.

THE BUFFALO, N. Y., WATER WORKS.

BY LOUIS H. KNAPP, ENGINEER, BUFFALO, N. Y.

[*Read September 15, 1899.*]

The city of Buffalo acquired by purchase the plant of the Buffalo Water Works Company in August, 1868, paying for the same the sum of $705,000. This amount was specified in the act of the legislature authorizing the city to construct and maintain a water works for the use of the city of Buffalo and its inhabitants.

The plant of the private company consisted of: First, about 34 miles of pipe, as follows: —

3-inch	486 feet
4-inch	51,629 feet
6-inch	79.375 feet
10-inch	19,667 feet
12-inch	9,045 feet
16-inch	11,489 feet
24-inch	7.304 feet
Total	178,995 feet

Second, one double Cornish Bull engine, made by I. P. Morris, of Philadelphia, in 1851, with a rated capacity of 4,000,000 gallons in 24 hours, and one beam engine, made by the Shepard Iron Works of Buffalo, N. Y., in 1866, having a rated capacity of 6,000,000 gallons in 24 hours; total daily rated capacity of pumps, 10,000,000 gallons.

Third, a tunnel 4 feet in diameter and 330 feet long; and fourth, a reservoir of 11,000,000 gallons capacity, on Niagara Street.

At the time of the purchase of the old works, a similar plant could have been constructed for about $500,000. These works have since been extended and improved to meet the demands of a rapidly growing city, until they are now among the largest in the country; in fact, our pumping station is the largest in the world under a single roof.

The following is a general description of the works: —

FIG. 1. — PUMPING STATION.

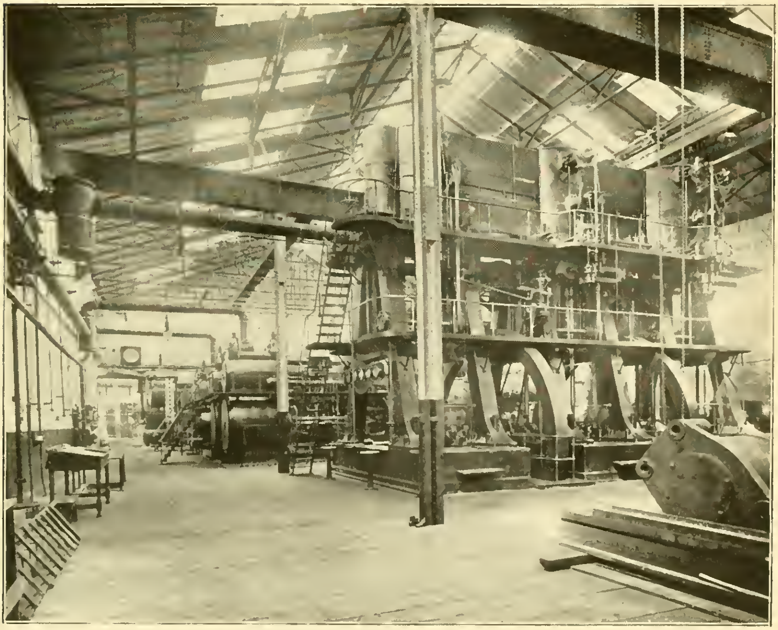


FIG. 2. — ENGINE ROOM.

PUMPING STATION.

The pumping station (Plate I, Figs. 1 and 2) is located on the Niagara River about two and one half miles from the City Hall, and contains the following machinery: —

PUMPING ENGINES.

No.	Capacity in 24 Hours, Gallons.	Makers.	Description.	Year Constructed.	H.P.
1	12,000,000	Worthington & Lake Erie	Horizontal Compound	1872, 1898	430
2	20,000,000	" " " "	" "	1876, 1898	700
3	20,000,000	" " " "	" "	1882, 1898	700
4	15,000,000	Holly (Gaskell)	" "	1885	550
5	20,000,000	" "	" "	1888	700
6	20,000,000	" "	" "	1889	700
7	20,000,000	" "	" "	1892	700
8	30,000,000	Lake Erie	Triple Expansion	1896	1,200
9	30,000,000	" "	" "	1898	1,200
	187,000,000	Total,			6,880

BOILERS.

North Boiler House — 14 horizontal return-flue boilers, with smokeless furnaces, 150 H.P. each — 2,100 H.P. 80 lbs. steam pressure.

South Boiler House — 14 horizontal return-flue boilers, with smokeless furnaces, 150 H.P. each — 2,100 H.P. 80 lbs. steam pressure.

6 horizontal return-flue boilers, with smokeless furnaces, 300 H.P. each — 1,800 H.P. 165 lbs. steam pressure.

Total H.P., 6,000

The station has an independent electric light plant for illuminating the buildings and grounds.

TUNNELS, INLET PIER, AND ICE ELEVATORS.

The water supply is received from the Niagara River through two tunnels, one of which has an area equivalent to that of a circle 6 feet in diameter, while the other has the same area as a circle 9 feet in diameter. The tunnels are parallel and about 30 feet apart; they are unlined and entirely through rock. Both tunnels are about 1,000 feet in length and terminate in the center of the river about one

mile from Lake Erie. The river shafts are protected by an inlet pier of cut stone masonry, finished in 1874 (Plate II, Fig. 1). The average depth of the water at the pier is 15 feet and the bottoms of the intakes are 6 feet above the bottom of the river. The current at the inlet varies from eight to fourteen miles per hour, depending entirely upon the wind.

During the winter months large fields of ice are continually passing down the river from Lake Erie, and to prevent the ice from entering the intakes the latter are protected with shields of steel plates from $\frac{3}{4}$ inch to 1 inch in thickness. These shields project out from the pier 2 feet and extend down to within 2 feet of the bottom of the river. They are provided with gates opposite the intakes which are somewhat larger in area than the area of the intakes. When the ice is running, these gates are closed and the supply is then taken from below the shields. In all ordinary runs of ice this is effective and entirely prevents any ice from entering the shafts.

There are times when the river is filled with "slush ice," extending down to the bottom of the river. Then this enters the intakes and shafts in large quantities and has to be removed as soon as possible. On the pier we have an ice elevator and also one at each shore shaft at the pumping station. The elevators at the shore shafts are shown in Plate II, Fig. 2. These elevators are placed upon a rigid framework extending 5 feet below the sills of the intakes and conduits. They are operated by steam and have a double row of perforated buckets working independently. The ice is elevated and discharged into the river or canal, according to the location, through chutes.

The closing of the intakes on the inlet pier by anchor-ice is prevented by raising and lowering the gates in the sides of the shields and running the ice elevator, and by a liberal use of steam and hot water, which is furnished by the boiler on the pier.

The conditions at Buffalo are peculiar and entirely different from those of any other city on the Lakes, and an uninterrupted supply of water during the winter months is only procured by constant care and watchfulness by the men on the pier and at the pumping station.

DISTRIBUTION.

The distribution system consists of 477½ miles of cast-iron pipe of the following sizes and lengths: —

FIG. 1. — INLET PIER IN NIAGARA RIVER.

FIG. 2. — ICE ELEVATORS AT SHORE SHAFT.

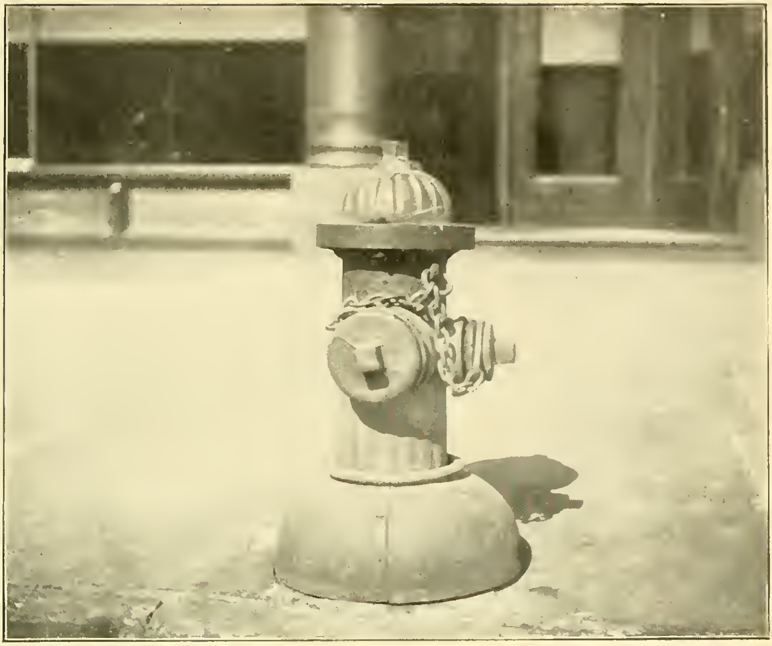


Fig. 1. — Buffalo Hydrant.

Fig. 2. — Hydrant with Steel Cover.

Fig. 1. — Hydrant and Call Box for Fire Boat Pipe Line.

Fig. 2. — Distributing Reservoir.

$1\frac{1}{2}$-inch	200 feet
2-inch	1,845 feet
3-inch	7,954 feet
4-inch	155,149 feet
6-inch	1,439,936 feet
8-inch	12,537 feet
10-inch	218,916 feet
12-inch	202,856 feet
16-inch	287,643 feet
20-inch	69,705 feet
24-inch	15,642 feet
30-inch	1,796 feet
36-inch	94,144 feet
48-inch	12,464 feet
Total	2,520,887 feet

The Buffalo hydrant, designed by the writer in 1882, is of the post type, and has a sole leather compression valve, 6-inch standpipe, one 4-inch and one $2\frac{1}{2}$-inch nozzle, and a 6-inch supply pipe (Plate III, Fig. 1). Where the hydrant is supplied from two 6-inch pipes at street crossings, an additional 4-inch nozzle is added. Where the hydrant is supplied by an 8-inch pipe, the standpipe is 8 inches in diameter, with two 4-inch and one $2\frac{1}{2}$-inch nozzles with independent valves.

There are 4,620 hydrants for fire purposes, all made to a standard and interchangeable. In winter these hydrants are protected by a steel cover or case for the convenience of the fire department (Plate III, Fig. 2).

The number of valves in use is 6,758. The total number of service connections is 63,284. The total number of meters in use, mostly large sizes, is 1,014.

The Fire Boat Pipe Line, constructed in 1897, is a 12-inch standard pipe with screw and lead joints, having hydrants and call boxes every 250 feet (Plate IV, Fig. 1). The length is 6,130 feet, the working pressure being 300 pounds per square inch; depth below the surface of pavement is 4 feet; capacity of pumps in the two boats is 10,000 gallons per minute. Each hydrant has four $3\frac{1}{2}$-inch nozzles with independent gates.

RESERVOIR.

The distributing reservoir, finished in 1893 (Plate IV, Fig. 2), is located about in the center of the city, and covers an area of about

20 acres. It has a capacity of 116,000,000 gallons. The elevation of high water is 116.60 feet above the water in the Niagara River at the inlet pier, or 684.68 feet above mean tide at New York.

For a detailed description of the reservoir, see *Engineering News* of January 10, 1891, page 26.

VALUE OF WORKS.

The estimated value of the works is about $9,000,000. The bonded indebtedness is $3,811,882.

CONSUMPTION.

In 1868 the population of the city was 100,000, and the average daily consumption 4,000,000 gallons, or a per capita consumption of 40 gallons. In 1898, thirty years later, the population of the city was 400,000, and the average daily consumption 89,000,000 gallons, or a per capita consumption of 222½ gallons.

The greatest amount of water pumped in twenty-four hours was on February 13 last, when the pumps registered 160,000,000 gallons, or a per capita consumption of 400 gallons.

The total amount of water pumped last year was 32,508,322,830 gallons, of which 40 per cent. was pumped on the direct service, 70 pounds pressure at the pumps, and 60 per cent. on the reservoir service, 50 pounds pressure at the pumps.

The average pressure maintained in the city is about 30 pounds per square inch.

REVENUE.

The annual amount received from all sources is about $700,000, of which $101,446.52 is derived from the sale of 4,785,000,000 gallons of water through meters.

EXPENDITURES.

The $700,000 collected by the department is expended as follows:

Salaries	$200,000
Interest on bonds	160,000
Fuel	54,000
Maintenance, repairs, and supplies	50,000
Extensions and improvements	236,000
Total	$700,000

CAPACITY.

The capacity of the two tunnels is estimated at 350,000,000 gallons per day. The maximum capacity of the present engines is estimated at 205,700,000 gallons per day. In round numbers, the capacity of the plant can be called 200,000,000 gallons per day.

WATER RATES.

Our meter rate to manufacturers is about two cents per 1,000 gallons. There is no meter rate to domestic consumers. The domestic rates are adjusted as nearly as possible to an equivalent of five cents per 1,000 gallons.

ADDITIONAL PUMPING STATION.

Plans have been prepared and approved for an additional station, with a minimum capacity of 200,000,000 gallons per day.

The proposed intake pier will be located in Lake Erie and will be of cut stone, provided with a receiving chamber and four gates, any one of which will exceed in area the area of the tunnel. The length of the tunnel will be 5,460 feet, and its cross section 128½ square feet, or nearly equal to a circle 13 feet in diameter.

In a comparison of the Buffalo Water Works with those of Boston, we find that although the population of Boston exceeds that of Buffalo by 50 per cent., the amount of water supplied to Buffalo exceeds that supplied to Boston by 50 per cent. The cost of the Boston Water Works was three times that of the Buffalo Works. The revenue received at Boston is four times the amount received at Buffalo. The operating expenses, the mileage of pipe, and number of fixtures in Boston are about double those at Buffalo.

DISCUSSION.

Mr. Geo. B. Bassett. A method of collecting rates from the different city departments has been recently established in Buffalo, and I should like to have Mr. Knapp explain that, so that it can go upon the record.

Mr. Knapp. We get from the fire department $20 for each hydrant, and we charge the public buildings, engine houses, schoolhouses, and places of that kind two cents per thousand gallons for the

water they use. The schoolhouses use a large amount, as the ventilating apparatus is operated by water power. The meter rates are two cents per thousand gallons to manufacturers. We supply no water through meters unless the consumer pays $24 a year. We collected from the city for water last year $110,000, and next year it will probably be in the neighborhood of $125,000.

Mr. J. C. Whitney. I should like to ask Mr. Knapp whether this large per capita consumption of which he speaks is owing to the extensive use for manufacturing purposes, or whether it largely represents waste?

Mr. Knapp. We figure that 70 per cent. of the water pumped is wasted.

Mr. Whitney. And yet apparently you discourage the use of meters.

Mr. Knapp. No, we do not.

Mr. Whitney. I was thinking about the $24 minimum charge.

THE METHOD OF REMOVING ORGANISMS FROM THE WATER IN THE DISTRIBUTING RESERVOIR OF THE CITY OF SYRACUSE, N. Y.

BY W. R. HILL, CHIEF ENGINEER AND SUPERINTENDENT.

[*Read September 13, 1899.*]

Before the American Water Works Association at Columbus last May, I read a paper entitled "How the Water Supply of the City of Syracuse Has Been Kept Free from an Unpleasant Taste." The subject is such a simple one that there is not much left for me to tell you to-day, but I have concluded to say a few words, calling to your notice some things which I would like to have you observe while you are here.

The source of our water supply is Skaneateles Lake, which is fifteen miles long, about a mile wide, and 350 feet deep. It is situated nineteen miles from the city, at an elevation of 466 feet above the Erie Canal. Our water is taken from the bottom of the lake, at a depth of 40 feet, about a mile and a quarter above the lower end of the lake. The water enters a crib connecting with a 54-inch supply pipe leading to the gate-house, from which we have a 30-inch cast-iron pipe to our distributing reservoir, which is situated at a point two miles from the center of the city, at an elevation of 221 feet. The water first reached the city from Skaneateles Lake in the month of July, 1894. It was then discharged into an old distributing reservoir which had an earth bottom. There was nothing peculiar about the water during the year it was distributed from this reservoir.

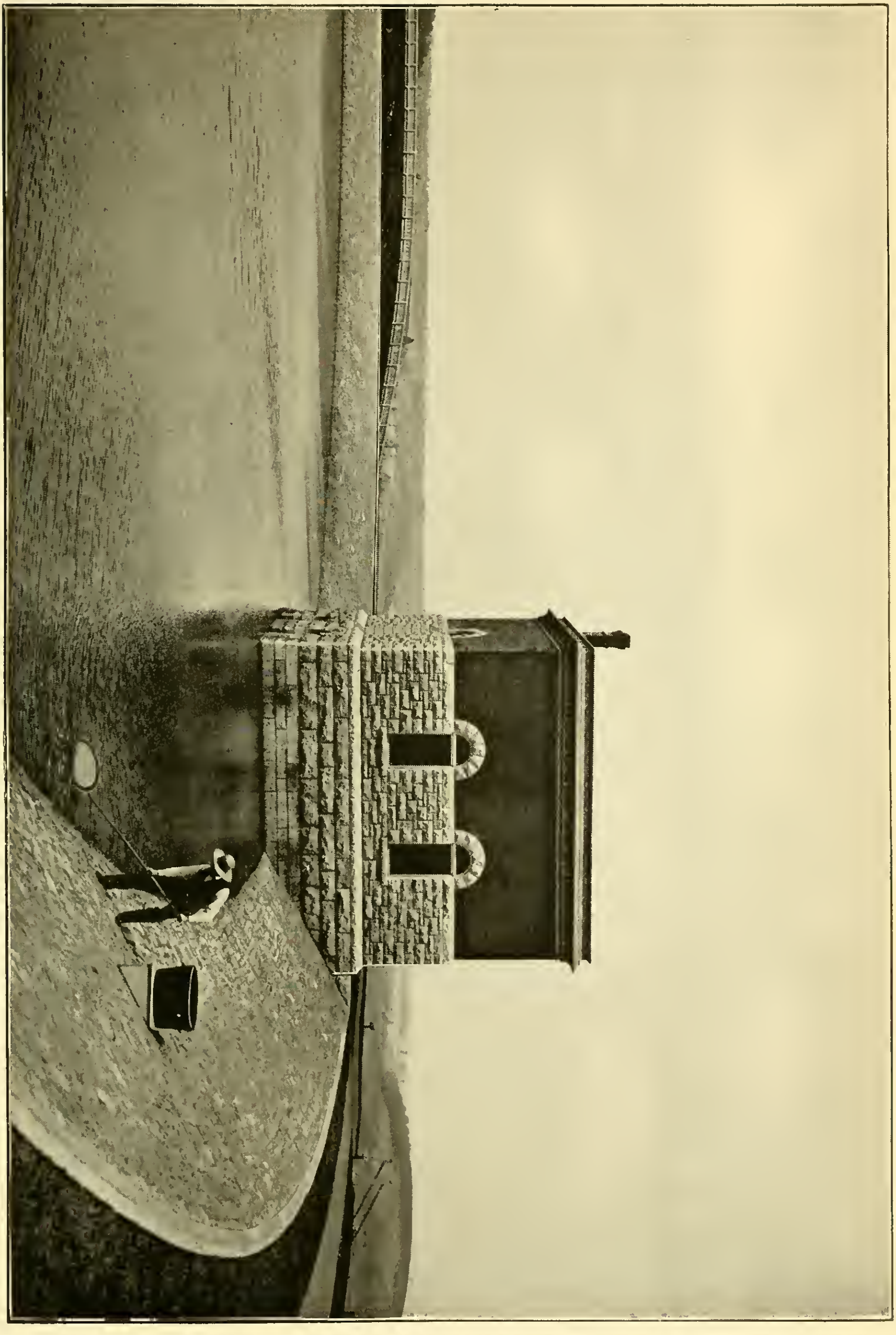
I would like to call your attention to the quality of our water. It is of excellent quality, clear, and of a bluish color. The greatest number of bacteria ever found in a cubic centimeter of our water is 26, as the result of examinations made every month during the last three years. In the winter time there have been as low as three and four bacteria in a cubic centimeter, and Dr. May reports that no organisms derived from fæcal matter, no sewage nor disease-producing germs were found. The chemical analysis of our water shows it to be of excellent quality, the solids, volatile and organic, being only

four and one half parts per one hundred thousand, the chlorine .4, the free ammonia .00052, and the albuminoid .0036.

But in spite of this fact, about the middle of May, 1896, when we were taking the water from our new distributing reservoir, which was lined entirely with cement, or stone laid in cement, a complaint was received at our office that the water tasted bad. Well, as you know, such complaints are likely to be received at any time, and so I thought at first it was merely from some crank, and I paid no attention to it. But on the day following the receipt of the first complaint our telephone was kept pretty warm by people calling us up from different parts of the city and wanting to know what was the matter with the water that made it taste so bad. I tried it myself then, and found it was bad. I drank it after I was told about it. Upon going to the reservoir, I found the water in it had a very disagreeable taste. Some might call it fishy, some might call it woody; I don't know what to term it. But the water coming from Skaneateles Lake in our conduit line was free from any unpleasant taste whatever.

I immediately caused the water from the lake to be turned into the distributing system, and emptied the pipes as quickly as I could by opening the hydrants on the outskirts of the city, and shut off the water from the distributing reservoir. I then emptied the reservoir and as the water lowered, the taste, or rather the odor — I don't know anything about the taste, because I don't believe anybody tasted it — increased, and when we got down to the bottom of the reservoir the stench from it was almost unbearable. On the shores, where it would be driven by the prevailing winds, there was found a gelatinous substance perhaps a quarter of an inch thick, and when this was uncovered by the lowering of the water it broke apart and curled up, looking like sheets of leather, and the stench from it was awful. In fact, people living off in the country, in the locality where we carted and dumped the stuff, came to my office and made complaints of the nuisance we were creating.

I then had the reservoir thoroughly cleaned and refilled it, and there was no further trouble that year. But in the spring of the following year, being fearful that perhaps we might experience the same trouble again, I had the water closely watched each day, and about the middle of May fine black specks were noticed floating on the water close to the shore. I had some of those skimmed off, and while they had a little odor, perhaps of a fishy nature, it was nothing



Removing Organisms from Water, Syracuse, N.Y.

very unpleasant or disagreeable, but in less than twenty-four hours the odor from this material was very strong. Continuing to watch the water closely every day, we found that these little specks were appearing on the side of the reservoir, close to the shore, where the wind would carry them. I had them skimmed off each day with a skimmer made of cheesecloth (see Plate I), and had the material taken quite a distance from the reservoir and buried.

That year a yellow substance also appeared on the water, in addition to these little black specks. It had the appearance of yellow corn meal floating on the water, and as the wind would carry the particles along they would form in little balls. The particles by themselves were so fine they would pass through cheesecloth, and we had to use a vessel to skim them off the water. That yellow stuff appeared for two years, but this year we have had very little of it, it appearing on only two days.

I have sent some of the material to Mr. Whipple of the Mt. Prospect Laboratory, Brooklyn, and he tells me that it is pollen from pine trees, plant heads, insect scales, water mites, etc. I have had the water along the shores of the reservoir skimmed for the last three years, and we have had no trouble whatever from any unpleasant taste. It is a peculiar fact that the water in the lake has never had the bad taste at all, and why it should have appeared in our reservoir, I will leave it for you to guess.

Now, on our trip to the lake to-morrow, I would like to have you notice particularly the shores, and you will see that they are free from any vegetable matter whatever, being composed almost entirely of shale rock or gravel. Another matter which I would like to call to your notice, which you will have an opportunity to examine at the reservoir this afternoon, is this material, which we have been skimming off daily for the last three or four months. I take perhaps a teaspoonful of the solid matter and put it into a bottle of water and have it labeled with the date it was taken off, and I would like to have you notice the different appearance of the samples taken on different days. You will observe that the sample of the water taken on one day is yellow, on the next day it will be green, and on the next day perhaps it will be perfectly clear. I would like to call to your notice also the unpleasant taste — no, not the taste, I won't ask you to taste it — but the unpleasant odor from some of the bottles. And I may say here that the odor from what we are gathering at this time of the year is nothing like as unpleasant as from that which

was taken off earlier in the spring. We are now having the reservoir skimmed each day, beginning the work early in the morning, and we shall probably continue to do it through this month and perhaps into the middle of next month. As the man goes around with his skimmer, it is almost impossible for him to notice anything on the water; he may have to go perhaps two or three hundred feet before he gets anything that will appear upon the skimmer, but by working all day long he will collect perhaps eight quarts of the solid matter.

DISCUSSION.

President Forbes. We would now be glad to hear from any one who has anything to say on the subject which has been presented by Mr. Hill.

Mr. J. C. Haskell. Mr. President, the subject of vegetable growths in waters is a very large one, it is quite a study in itself, and many water works have been driven to the establishment of biological laboratories for the constant daily study of these phenomena, which, as Mr. Hill has suggested, sometimes change with great rapidity, so that samples taken at intervals of a week or so are totally inadequate to show the nature of the changes which are taking place. I am a little disappointed not to learn from Mr. Hill the nature of the organisms which caused this odor which gave him so much trouble a few years ago. From the result of the examination which he has given of this scum, showing as it does that it is composed of miscellaneous débris, it would seem to me hardly likely to give rise to a generally offensive odor throughout the water. Material of that kind in a comparatively limited quantity of water will decompose and produce a bad odor; but the little insects and the débris from pine trees, and the other things which he mentioned, as far as my experience goes, are rather inert in large bodies of water, and are not likely to give rise to the odor he has described; and it would seem to me on the face of it that this material must be rather aside from the real cause of the trouble, and that there must have been some organism of quite a different nature present in large quantities in the water at that time to have given rise to the odor. I would like to ask Mr. Hill if he has made any observations at other times, and if he has looked for Asterionella or Anabæna, or anything of that sort distributed through the water which might account for it.

Mr. J. B. Fish. I would like to ask Mr. Hill, or any other

gentleman, to tell me how he would class this substance of which Mr. Hill has spoken as curling up. I found it once in my reservoir, covering everything on the shore. It did n't extend out beyond four feet in depth, but everything within that depth, even a twig that might be in the water, was covered with this jelly-like substance. I tried to preserve some of it to send to Professor Lee for his examination, but it soon became so offensive that I had to throw it away. Does any gentleman know how to class that among the algæ? I believe there are about 996 different species.

Mr. Hill. I regret to say that I cannot give more light on the subject of what this material is. I will say this, that early in the spring I filled a half-gallon bottle nearly full of the solid matter and saturated it with water, and the odor was something awful. Professor Englehardt was in my office one day, and I showed it to him and asked him how many gallons of water he thought that would contaminate. He held up his hands and said, "Why, Mr. Hill, hundreds of thousands of gallons." I think there is no doubt that a small quantity of this substance would contaminate a large body of water.

The President. I would like to ask Mr. Hill if this skimming process is supposed to remove the spores of some kind of animal or plant, before they get a chance to grow, and thereby to prevent the plant or animal from developing.

Mr. Hill. Yes, sir.

The President. Can any one in the room answer the question asked in relation to that jelly-like substance? I know from my own observation that it may come from several things, and you never can tell exactly what it has come from unless you have an opportunity to make a careful examination when the thing is there. Sometimes it may be fish spawn, or it may be snail spawn, and there are various kinds of jelly-like substances which do form on sticks and on stones and on a muddy bottom, and the only way to determine the source of it is to get a sample and have it analyzed before it decomposes and breaks up. Perhaps some one in the room can tell more about it. I know Mr. Haskell can.

Mr. Haskell. I have had quite a little experience with these jelly substances. I have seen masses as large as two feet in circumference rolled along in our canal as the water was running down towards the pumping station. It might not be the same jelly-like substance which made this particular nuisance in Mr. Hill's reservoir,

but I find in all cases the substance has a very pungent odor. I gathered some of it last Monday and took it to the laboratory to have it examined. I would n't care to state what it is, because it had not been examined when I left home, and it is quite uncertain what it may turn out to be, but it had a very offensive odor. We have had this jelly substance in our water supply every year, more or less abundantly. I am not able to tell what causes the formation of the substances of which Mr. Hill has spoken; and in considering this matter of the skimming, it occurred to me that we don't very fully understand it, because we don't know how the water is taken from the reservoir down to the city supply. I should suppose that these substances would almost always be found at the leeward side of the pond. I know we find that these little organisms will sweep across our pond at the rate of a mile a day when the wind blows heavily. I have seen them on one side of the pond in the morning, and the next day I have seen them on the other side, and the water which was full of them the day before would contain none whatever then; and if the wind shifted they would go back again to the other side. Now, if the water was taken at a depth below the surface, organisms that were on the surface would not affect the lower water, unless there was something worse than an odor. The odor would not go down through the water, but it would escape into the air, unless the whole body of water was impregnated with the organisms. If we can skim our ponds so nicely that we are not going to get these algæ odors in the water, it seems to me it is a pretty good thing. We have n't been able to do anything of the sort with our ponds, although we have done more or less experimenting in that direction. We have found that we will get odors when certain organisms that cause them are in the water. Of course we know that a very small amount of a very pungent substance will go through a whole reservoir and contaminate it. I should have been very much pleased if Mr. Hill could have told us that they had suspended the skimming process and had then found that the odor continued, for of course that would have been a proof that it was there and was something serious, and that the skimming was doing a valuable service. It is very evident that at one time there was a bad odor there; but with such very pure water as there was in this lake, water that can be called absolutely pure, turned into a reservoir of solid masonry, and under the very best conditions possible, it does seem to me as though it had n't been fully demonstrated to us that there would have been a bad

odor in the water this present year if there had been no skimming. I make this suggestion from the fact that if there is n't more than a bucketful of skimmings obtained as the result of a day's labor, and the water was taken in from the windward side, it does not seem to me as though the skimming would have cut any figure whatever. I simply make that as a suggestion, although I do hope that the skimming is a good thing.

Mr. Fish. We have two or three bodies of water in our works, and they have their seasons of fermentation, during which time there will rise to the surface that peculiar weed which grows up and decays. It appears very rapidly, and it will blow over to the leeward side of the pond, where it will be so thick that it would almost seem as if you could walk on it. But the moment you stir it, it dissipates itself all through the water, and is too fine to do anything with, except when it gets together in a mass. It would be almost impossible to skim it, and if Mr. Hill has any device which will work on that I would like to see it, for it seems to me that if it would work I could skim off a cartload at a time. One of our reservoirs in particular we have to abandon while it is going through this process of fermentation. We happen to be so situated, having two impounding reservoirs, that when one is bad we can shut it off and wait until it purifies itself. But we have something else which is even worse than this. Professor Lee tells us that we have germs which will grow in the pipes so that you may start with artesian well water, as pure as you can possibly conceive of, as pure as Skaneateles Lake water, and after it has run three miles through the pipe it will be totally unfit for use. That is what he calls "the devil of the algæ," and it actually grows in the pipes. In the winter time it does n't appear, but in the summer, when the temperature gets to the proper height, it accumulates beyond all count.

Mr. Allen Hazen. Do you remember the scientific name of "the devil of the algæ"?

Mr. Fish. I do not; he merely called it "the devil of the algæ." You will find it in the report of the meeting of the American Water Works Association at Chicago, I think.

Mr. H. C. Hodgkins. I would like to ask Mr. Hill whether he has ever observed what is called blossoming in the water.

Mr. Hill. No, sir, I have not.

Mr. Hodgkins. I might say that I have had some experience in which the efficacy of skimming has been demonstrated. The material

as it appeared in the water was of a greenish color, a good deal like vegetable substance, and for three or four days there would be a very strong odor, and then all at once it would disappear. I had understood that that was quite common to find in the waters of our interior lakes, like Skaneateles Lake, and I supposed when I first heard of Mr. Hill's plan of skimming that he had also discovered what I have been led to call blossoming. It is quite pronounced in some of the branches of Lake Ontario, and the growth is perhaps similar to what the gentleman who last spoke has described. It will grow to look something like water cress, and when you stir it up it is disseminated quickly. There does not seem to be much substance to it, although if it could be gathered together you could get out quite an amount of it.

Mr. Hill. I would like to call to your notice the fact that this material, as we take it off from day to day, all has the same appearance, or nearly the same, when first taken off; but after it has been kept for some time it changes into all sorts of different forms and colors, as you will be able to see in the bottles at the reservoir.

Mr. Haskell. I would like to ask Mr. Hill if there have not been any microscopical examinations of the water. I think it is always absolutely certain that you can find out what gives a peculiar taste or odor to a water. I know that scientific men claim they can tell you just what it comes from, and I have n't any doubt that they can; and I do not question at all that at some well-conducted laboratory they can tell us exactly what we have got to combat in any given case. We ought to know what we have got to fight against before we undertake to fight it.

Mr. Hill. I quite agree with Mr. Haskell that such examinations as he suggests should be made, but to be of much value they should be made from day to day for quite a long period, and it would be necessary to have the examinations made of fresh material right here in the city; and as yet I have not had an opportunity to have that done.

ON REMOVING ORGANISMS FROM WATER — A DISCUSSION.

BY DR. FREDERICK S. HOLLIS, BIOLOGIST, METROPOLITAN WATER WORKS.

[*Read December 13, 1899.*]

The paper presented by Mr. Hill at the convention last September is a very suggestive one. It is a record of the fact that growths may occur without apparent cause and to an extent sufficient to render the water unfit for use in a reservoir supplied with pure water.

It is to be regretted that the exact nature of the particular growth which caused the difficulty was not established beyond a doubt, as it is only by means of such definite information that we are enabled to use the knowledge gained from such experiences in a way to guard against future occurrences. The identity of such growths can be established with certainty only by a carefully conducted microscopical examination of the fresh material. As no definite information has been given concerning the nature of the growth which caused the difficulty in the distributing reservoir at Syracuse, it can be commented upon only in a general way; rather with a view to encourage a more careful examination in the future than to indicate the cause in this particular case.

Very few, if any, waters exist which will not support a considerable growth of some form of microscopic organism, just as few soils exist that will not support a plant growth of some form, while the exact variety of microscopic organism which will thrive in a particular water varies greatly according to the nature of the water and the season, as does the form of plant which will thrive on a particular soil. In agriculture and forestry advantage is taken of the capability of different soils in selecting most suitable crops, and sufficient knowledge has been gained already in the study of growths in water to enable us to judge in many cases what, within certain limits, may be expected. It is known as the result of experience that a pure, color less ground water generally contains plant food in sufficient quantity to support a vigorous growth of vegetable life if exposed to the light,

or if the other conditions favorable for the support of such life are present. When the food supply of the water is thus converted into a vegetable growth, it becomes available food for other and higher forms of life. On account of this accumulation of food material, a storage reservoir commonly deteriorates from year to year as judged from the standpoint of microscopic organisms, even though it receives a comparatively pure water originally free from such growths. If the organisms of the different classes found in a new reservoir are plotted on a regular scale for each year from the time it is first filled, it will be seen that the variety of forms increases with each successive year, and that the number of each class also increases.

For that reason I believe that it is fortunate that in most supplies it is generally necessary to draw down the water of the reservoir regularly, which serves to remove the accumulated food material.

In the study and care of a supply it must be remembered that these growths, both animal and vegetable, are, as a rule, delicate and dependent for a vigorous growth on the exact conditions of food supply, temperature, and light. If all the conditions are not favorable the growth will not assume proportions sufficient to cause trouble, although it may appear to a limited extent. I cannot emphasize too much the fact, which I have mentioned before the members of this Association at other times, that the value of such examinations depends very largely on the personal study of the source by the biologist or chemist who is to make in the laboratory the examination of the samples collected, for it is only by such observation that one is enabled to judge of the conditions under which the growth is taking place.

The process of removing material from the surface of a water supply by skimming is certainly valuable in many cases, and is practised to advantage, but is mainly useful in removing growths already established or which have begun to decay and are being brought to the surface by the attached bubbles of marsh gas, which is a product of decay.

The successful removal of a large quantity of a growth of Anabæna which had thus risen to the surface and collected at one side of a body of water by the action of the wind came to my notice this summer.

The method of skimming should never, I believe, be relied upon as a means of removing the cause of the growths of microscopic organisms, as it would be inadequate in the case of those forms which are

most frequently the cause of serious trouble. The spores from which such forms originate are generally not present at the surface, and, even if they were, the method would fail to remove them on account of their minuteness. The rapid development of any particular form is, as has been already stated, dependent upon the presence of all the conditions favorable for its growth. Such favorable conditions are frequently brought about by the mixing or overturn of the water of a reservoir by the action of the wind or through an increase of density of the water of the surface, due to change of temperature, thus bringing the accumulated food material from the bottom and making it available at a point where the other conditions favorable for growth are present.

Such a rapid development is frequently spoken of as the "working" of the pond, and such working has been reported for growths of Clathrocystis, Anabæna, and Uroglena. In such cases the method of skimming the surface would clearly serve little purpose in removing the cause of the growth.

By means of frequent microscopical examinations of the water during a period of growth, the zones or depths to which this particular organism extends can be determined accurately, and it is common to have the conditions such that a perfectly good water can be drawn from depths not affected in a reservoir for a long time, and frequently for the entire period of growth of a form which is confined to a particular depth or zone. At no time since the establishment of the laboratory of the Metropolitan Water Works has the value of the work been more apparent than during the present year, when the limited rainfall has made the systematic economy of the water of the impounding reservoirs necessary; and it has been necessary in many cases to draw on certain reservoirs as far as possible before discontinuing their use on account of the presence of a growth.

DISCUSSION.

Mr. W. R. Hill. Since the September meeting of this Association I have had further correspondence with Mr. G. C. Whipple in relation to an examination that he made, about the middle of June, 1899, of a sample of material collected from the surface of the water in the distributing reservoir at Syracuse. He requested me to note that, in addition to pollen from pine trees, plant hairs, insect scales, insect larvæ, water mites, and other similar objects, he found stato-

blasts, or eggs of the Plumatella, and that he would expect the extraneous substances to vary from time to time.

In order to form a complete list of the scientific names of the organisms it would be necessary to make a microscopical examination each day for an entire season, and I fear that this information would be of little or no value to enable us to guard against their development, because of the fact that, like the vegetation from the soil and the insects in the air and earth, there are many different kinds, varying wonderfully in their character as developed in their own particular time.

I doubt if any successful means could be devised to prevent their appearance except perhaps by covering the reservoir, or by regularly emptying and cleaning it, and refilling it with fresh water. If this latter method could be made effective, it must be acknowledged that it could not be done without considerable expense and a great waste of water at a season of the year when there is usually the greatest consumption, and when there would most likely be a scarcity of water.

Dr. Hollis states: "If the organisms of the different classes found in a new reservoir are plotted on a regular scale for each year from the time it is first filled, it will be seen that the variety of forms increases with each successive year and that the number of each class also increases." This fact emphasizes the important and effectual results that have been obtained by skimming the water in the distributing reservoir at Syracuse. This reservoir was first filled with water about the middle of August, 1895. On the twentieth day of May, 1896, or after a period of only nine months, the water became so foul that it was unfit for use. The reservoir was emptied and cleaned. On the tenth day of July, 1896, it was refilled with water, and after that the city was supplied from it. In the spring of 1897, after close observation, the organisms were first noticed and the method of skimming was then put into practice. Since then not even the slightest disagreeable odor or taste has been observed in the water, nor has the reservoir been emptied, even though the variety and number of organisms are expected to increase from year to year.

In this connection I would call to your notice the significant fact that fewer bacteria have been found since the water has been skimmed. In the years 1897, 1898, and 1899 the greatest numbers found in a cubic centimeter of water were 19, 20, and 22 respectively, while in the year 1896, 26 were found, and in the year 1888, in a sample of water taken from the lake, 39 were found.

Each day during this season I have preserved a sample of the organisms in a bottle of water, and it has been very interesting to notice the many effects it has had upon the water, changing its color to green, yellow, pink, drab, and other shades. On some days the organisms would blacken the water, which on the following day would be clear and merely tinted. The odors changed from day to day. The most disagreeable odor was from the matter collected in the spring.

Mr. Whipple states that in his opinion it is quite doubtful whether the impurities taken from the surface of the water were the cause of the trouble, and that he would sooner think that it was due to some microscopic organisms which afterward disappeared. I think that if Mr. Whipple could make an examination of the substances taken early in the spring he would find organisms that would lead him to change his opinion.

I regret my inability to give a complete list of the names of the organisms which have been skimmed from the surface of the reservoir during the last three years. Nevertheless, they have been of such a character that when first taken from the water they had little or no odor, but after decomposition they have produced the most foul, offensive, and disgusting odor imaginable. In the year 1896, when the reservoir had been in use but a short time, numerous complaints of a disagreeable taste and odor to the water were received. These objectionable phenomena have been conspicuously absent during the last three seasons when the skimming process has been in operation, and I fail to see how their non-occurrence can be ascribed to any other cause except to the precaution of skimming.

Mr. R. S. Weston. I would ask Mr. Hill if he does n't think that weekly examinations of the water would reveal the character of the growths in it? Nearly all of the organisms which are found in water supplies require three or four days for their growth, life, and disappearance, and if weekly examinations were made they would pretty thoroughly cover the life period of most of the organisms.

Mr. Hill. I would say that perhaps you are right in that statement.

Mr. J. C. Haskell. Mr. President, I would like to ask Dr. Hollis if he could not tell us a little more explicitly about the effect of drawing the water at varying depths; whether a better quality of water might not be obtained than by drawing from any fixed location, either at the top or at the bottom.

Dr. Hollis. I have in mind two reservoirs where we have been drawing from the bottom practically all summer with very good results. Fortunately we had no really bad growths there. Such as we have had have been mainly surface growths, and we have avoided them to a great extent by drawing from the bottom, the draft being in such quantities that there was no stagnation. Then, again, in another reservoir there was a growth of Cyanophyceæ mainly at the surface, and the water was drawn at a depth where there were practically none of the organisms.

A Member. How deep was that?

Dr. Hollis. One of the reservoirs was nearly 70 feet deep, one 20, and the other 40. So it seems to be a matter of very little moment how deep you draw, so long as you avoid the growth, which tends to keep at the surface. We were quite as successful in the 20-foot reservoir as in the others, getting water comparatively free from the surface growth.

Mr. Horatio N. Parker. I should like to call attention to one point in Mr. Hill's paper. He speaks of taking this matter from the reservoir, keeping it in a bottle, or at least a portion of it, in suspension in water, and then noticing the different odors from time to time. I think almost any organic matter when confined in that way would emit an offensive smell. It seems to me perfectly possible that he may have there organisms which are quite harmless in themselves, and which would not cause any trouble in a water supply, but which when bottled up would produce an offensive odor; and that it is not exactly fair for him to assume, as I understand he does, that because these organisms produce an offensive odor in a bottle they would at all injure his supply.

We have found as the result of our examinations for a great many years that there are certain definite organisms which cause certain troubles at certain times. We know them perfectly well and we are very careful of them. Mr. Hill may have had them at a certain time in Syracuse, and perhaps has never had them since. Whether that is due to his very effective cleaning of the reservoir or to his skimming may be an open question, but it seems to me that it would be rather due to his effective cleaning. We know that the seeds of those organisms, for such the spores really are, will develop if the conditions are suitable. We may have a reservoir not causing any trouble for years, and then all of a sudden, within a week, one of these organisms gets a foothold there and causes trouble, and we biologists have to hustle and do the best we can for the city.

It seems to me the point of this whole matter is, what is the best way of dealing with growths? Shall we skim our reservoirs, or shall we make regular examinations of the water, study the organisms and the conditions under which they occur, and act on the results gathered from such investigations? It might have been possible for Mr. Hill, when that big growth appeared, to have drawn from his reservoir in such a way as not to have disturbed the consumers; on the other hand, it might have been impossible. At any rate, there is a point that the laboratory might have settled. It seems to me that any superintendent is going to be benefited by a laboratory. It cannot always help him, but he will always be glad of the information that it will give him. While Mr. Hill's skimming in this case may have been effective, I doubt very much if it would be under all circumstances. It seems to me, as Dr. Hollis has said, that while it may be a good thing to do sometimes, it is only in extreme cases that skimming can do any good.

Mr. Hill. I perfectly agree with the gentleman; I think the biologist would give us a great deal of valuable information with regard to the character of these organisms. Nor do I want to be quoted as saying that I think the method of skimming can remove all kinds of organisms from water. With regard to preserving these samples in a bottle of water, it is quite commonly known that when any vegetable matter is confined in a water-tight vessel it very often preserves it. I might have said, however, that in addition to keeping samples of the material in water I have from time to time kept them in bulk, and the odor from it was disgusting, very strong. So the odor is not due to the corking up of the material in a bottle.

Mr. Parker. May I ask, Mr. Hill, if when you kept them in bulk the conditions were such that they would grow?

Mr. Hill. Oh, no. I just took the material and rolled it up in a ball and kept it over night, and the next day it would be very offensive.

Mr. Parker. I should think under those conditions decay was probably taking place.

Mr. Hill. Certainly.

Mr. Parker. And that would cause the offensive odor.

Mr. Hill. Yes, sir.

Mr. Parker. Whether that stuff alive passing through your pipes would cause any trouble I should think might be an open question.

Mr. Haskell. I would like to ask Mr. Hill if he has any idea about the bulk of a day's or two days' skimming; for the amount would have a good deal to do with the damage it would do to the water.

Mr. Hill. I should say we had taken as much as a peck of solid material off in a day.

Mr. R. C. P. Coggeshall. Will you briefly describe the apparatus you use?

Mr. Hill. It is an iron frame, about two feet in diameter, covered with very fine cheesecloth. The man walks along the shore close to the edge, and gathers up what might appear to be foam; he can see nothing on the water, but by constantly working over it he gets this material, and after it has been kept for twenty-four hours, either in water or in the open air or in a vessel of water without any cover at all, the stench from it is awful. In fact, the year we had the trouble, when we emptied and cleaned our reservoir, you could notice the smell a thousand feet away.

Mr. Parker. Did n't you, in your paper describing the trouble, Mr. Hill, write of a jelly-like growth which accumulated on the sides of the reservoir?

Mr. Hill. Yes.

Mr. Parker. May I ask you if that was offensive to the smell when collected on the reservoir?

Mr. Hill. Very offensive.

Mr. Parker. By this process of skimming was this jelly-like growth removed?

Mr. Hill. No. After the matter had decomposed it would form a jelly in the bottom of the bottle.

Mr. Parker. Did the skimming remove any of this offensive jelly?

Mr. Hill. No. We have not observed the jelly since the first year, when we first had the trouble and drew off the reservoir. Since that time we have noticed no jelly, and the reservoir has not been emptied since.

Mr. Parker. Then you found the jelly after you had drawn down the water?

Mr. Hill. After we had drawn down the water, yes.

Mr. Parker. Then you think it possible that that jelly which was offensive in its smell might have existed in the water and not have been removed by your skimming?

Mr. Hill. I think in removing the organisms we removed the cause of the formation of that jelly.

Dr. Hollis. I have had a little experience during the past summer which has shown the difficulty of transporting these organisms. In one city, for which I had formerly made a study of the water supply, they were troubled with a growth of a species of Polyzoa, a form somewhat larger than those that commonly cause trouble in water supplies; and while nothing was said about its giving any odor or taste to the water, it did cause considerable trouble in the meters. Samples have been sent to me at three different times for the purpose of having me examine and report upon them; but I have never received them through the mail the short distance which they came with the form of the organisms preserved. The jelly-like organism had entirely decomposed in transit, and only the sheath remained, from which I could judge that they were Polyzoa.

A RUMPUS IN COLLECTING METER RATES — CAUSES AND CONSEQUENCES.

BY GEORGE F. CHACE, SUPERINTENDENT, TAUNTON, MASS.

[*Read December 13, 1899.*]

At the annual meeting of June, 1889, when I had had one year's experience in water works affairs, I had the honor to read before this Association a paper entitled "Friction in Collecting Meter Rates." I realize now, ten years later, that to some of my confrères who had been connected with water works management for a long period, my effusion at that time must have seemed to have that freshness, that guileless confidence in human nature, that sublime faith of the theorist who knows little of practice, which entertain me when I listen to the earnest, well-meaning exhortations and advice of some good clergyman about the conduct of political affairs, — a clergyman who may be an excellent Greek scholar, an orator and a Christian, but who is profoundly ignorant of the practical difficulties of municipal government.

The collection of meter rates in January, 1898, I am not likely to forget. The difficulties with which I then had to contend I think I can most clearly and concisely set before you, if I begin by stating that they led to the passage of the following order by the City Council on January 18: "That the Joint Standing Committee on water be and are hereby authorized and directed to thoroughly investigate the meter system of the Water Department and report to the City Council the result of their investigations; and it is further ordered that the Board of Water Commissioners furnish said committee with all necessary information."

I prepared myself for the ordeal and appeared before the Joint Standing Committee on Water on February 16. To save repetition, I will here incorporate the communication which I read to this committee: —

"TAUNTON, February 16, 1898.

THE MAYOR AND GENTLEMEN OF THE JOINT STANDING COMMITTEE ON WATER:

In accordance with the order passed by the City Council on

January 18, and the notice sent to the Water Commissioners of the meeting this evening, I appear before you in behalf of the Commissioners, to give you such information as lies in my power in regard to the meter system of the Water Department.

November 30, 1887, the Water Department had in use 776 meters; 58 of these were classed as manufacturing meters, or meters of large consumers who paid quarterly rates, and 718 were called domestic meters. My own connection with the Water Department began April 1, 1888. Previous to that date, although the meters were read regularly once a month and a record of repairs kept upon sheets similar to these exhibited here, there was no regular and systematic testing of meters, and no means of ascertaining the history of any particular meter without examining many books and sheets. When consumers or the department desired a test, this was made by comparison with the record of a test meter, which was accurate to within one per cent. of actual flow.

The meters were read by a man who was engaged most of the time upon service work. Repairs were made under the direction of the foreman, sometimes by himself, sometimes by a man set at the work by him, and sometimes a meter which was out of order was sent to the makers to be put in order by them. The work upon meters kept increasing from year to year.

In April, 1889, the tank and scales which you see in the photograph here presented were purchased at an expense of $95.45, for the purpose of accurately testing meters, whenever an occasion required. The tank will hold 36.74 cubic feet of water, or 274.83 gallons, when level full. It was intended to hold conveniently 30 cubic feet of water.

It was the intention of the superintendent, after the purchase of this apparatus, that no new meter should ever be set without being tested in the shop. But, owing to a multiplicity of work, and the fact that no one man had full charge of the meter business, this purpose was not fully carried out until April, 1893. About eighty tests were made between Aprll, 1889, and April, 1893.

From April, 1889, to January 29, 1898, 4,818 tests have been made and recorded. As on an average two tests have been made to each meter, this means that we have tested about 2,400 meters. These meters have varied in size from four inch to three-eighths of an inch inlet and have included at least a dozen different styles of meter.

Since 1889 we have had one book which gives the history of every meter from the time it was first set. The record in this book shows when the meter was set, its reading when set, taken out, and reset, as well as the purpose for which it was removed and the service where it may be found ; and when worn out and thrown with the junk, this book shows that fact.

Beginning with April, 1893, it was made the business of one man to look after meters. He was ordinarily supposed to do nothing else but read meters, and see that they were tested when necessary and kept in order, and to set new meters. That the work might be done more thoroughly, it was soon found desirable, as the meters multiplied from year to year, to give him an assistant, and now, for several years, two men have been kept busy in the meter department.

To give you an idea of the work, I may mention that in 1897, besides the monthly reading of 1,536 meters, these two men set 95 new meters, each one of which had to be tested for at least two streams before setting, and took out 308 old meters, 77 of which were thrown in the dump and replaced by new meters ; 21 were frozen ; 15 were discontinued ; 62 were taken out ; 10 were sent to the makers for repairs ; 122 were repaired in the shop ; and 226, after being tested and put in order, were reset upon the same service.

The cost of maintenance of these 1,536 meters, including reading and repairing, has been about ninety-four cents per meter.

Ordinarily, we do not have much trouble in the settlement of meter rates. It has been the custom for a number of years, as a matter of courtesy, to notify consumers when their apparent consumption is larger than usual. Consumers have come to regard these notices as a right.

Until this year we have had only a few each January who grumbled at the size of their bills, and we have had occasion to make only a very few abatements, and these more for the sake of giving the consumer the benefit of the doubt than for any other reason. Of course, there will occasionally be a clerical error or mistake in the reading of a meter, and such errors we are always glad to rectify.

In January, 1898, we had an unusual amount of trouble. To explain the cause of this trouble is the principal reason why I am here to-night. I noticed a year ago that the receipts from meters were much smaller than for the previous year. I attributed this, for the most part, to the depression in business, especially as I noticed the

quarterly meter rates for January, 1897, were much less than for January, 1896. But subsequent developments pointed out another cause. One gentleman called my attention to the fact that his bill was only ten dollars, when he had been paying from fifty to seventy. This led to an investigation, and I found that the young man who was supposed to read the meters had been known to skip some services and put down a plausible reading on the book, so that I would think he had read the meter. Of course we had no further use for him. But he had been putting down readings which were too small. His last work was in January, 1897. When the correct readings were made in February, there was an apparently large consumption for January. The real fact was that what appeared to be a consumption for January, 1897, should have been spread over the previous year.

I have already said that we had on November 30, 1897, 1,536 meters in use; 150 of these paid quarterly rates. Of the remaining 1,386, which we call domestic meters, 793, or about 67 per cent., were charged the $10 minimum rate; 593 were charged more than the minimum rate. Nearly half of the people who had these bills to pay claimed that their meter rate this year was excessive, and some of them protested vigorously against paying without some abatement. The Commissioners, knowing the cause of the difficulty, left it to my discretion to settle the bills as amicably as I could, in a manner as equitable as possible to both parties.

The clerk who makes out the bills was alarmed at the large increase in the amounts of many of the bills, if made out according to the meter readings. I have no doubt the full amount as charged according to the readings, in most cases, belonged to the Water Department, although some of it should have been paid last year, and even in 1895, rather than to have so large a bill for January, 1898. What I mean to say is, that, in many cases, where if the reading had been honestly returned, the bills for the past three years would have averaged, for example, $15, as a matter of fact, the consumer was charged $10 in January, 1896, $10 in 1897, and $25 in 1898. The amount paid for the three years would be the same in both cases, but the consumer would naturally be alarmed at a 250 per cent. increase in his rates for the payment of January, 1898.

Under the circumstances, I thought the wisest way was to treat the apparently large consumption for January, 1897, as if it were a large leak, and, as we have sometimes done in cases of very large

leaks, divide with the consumer. Abatements were made upon that principle, and in many cases before the consumer had seen the original bill at all. Some rates we were able to settle on that basis. But the opposition was so strong and there were so many claimants for abatements that, finally, whenever the large bill was due to the big jump in January, 1897, I took the difference between the readings of February, 1897, and December, 1897, divided by ten, and multiplied by twelve, thus charging the consumer for the first two months of the year 1896–97 the average of the readings which had been correctly taken and recorded.

This was the basis on which most of the abatements were made. Sometimes when the bill was still much larger than usual, and when the consumer was extremely persistent, for the sake of peace further concession was made, which in a very few instances amounted almost to a dicker. In some cases I could see no reason for any concession, and no abatement was made.

The net result was 261 abatements out of 1,536 meter rates. The meter rate receipts for January, 1898, were, after all, $3,956.73 larger than in January, 1897, and $875.17 larger than in January, 1895. So that now, instead of falling off in receipts, as there was last year, we have for the three years a natural and steady increase, but unevenly distributed because of the facts I have mentioned.

In many cases I had the meter tested, but although there was occasionally a small over-registration, the amount over at the most was a small part of the bill. In 161 cases where we had record of tests, over-registration of the meter would not entitle the consumers in all to more than $63.16, and if we subtract those cases where the registration was in favor of the consumer, not more than $30.38. That is an average of eighteen cents for each meter. The average of the 4,818 tests we have made is 0.7 of one per cent. in favor of the consumer. A meter will sometimes over-register when it contains a good deal of sediment, but only to a moderate degree.

The trouble, then, is practically never with the meter when a consumer has a large bill. Either the water has gone through the meter or there has been a mistake in the reading. The latter is easily corrected.

I know, from actual experiment, that 25,000 gallons will pass through a ½-inch meter in twenty-four hours. Any consumption between nothing and 365 times 25,000 gallons is possible for a ½-inch meter. It is absurd for a householder to expect, as some do,

always to keep his bill down to the minimum rate, even when he has two or three families, with all the chances of leaks and careless waste.

Gentlemen, I am sorry we have had so much trouble, but an experience of ten years, with more than 2,000 meters, ought to be worth something. Men are not infallible. I must trust somebody. I cannot personally do the work of the whole Water Department. I will supervise it to the best of my ability, and endeavor to have as little friction as possible with the citizens of Taunton. I think you understand the chief cause of the meter rate excitement of the present year.

In behalf of the Water Commissioners,

Respectfully submitted,

George F. Chace,

Superintendent."

After this communication had been read the committee cross-examined me at some length. They reserved their decision, and at a subsequent meeting summoned the Water Commissioners, who appeared with me and fully sustained the position I had assumed.

The following is the report of the Joint Standing Committee under date of March 10, 1898 : —

"CITY OF TAUNTON.

In Board of Aldermen. The Committee on Water, acting under the instructions of the City Council, begs leave to submit the accompanying report: —

In accordance with an order adopted by the City Council on January 18, 1898, directing the Joint Standing Committee on Water to thoroughly investigate the meter system of the Water Department and report to the City Council the result of their investigations, the committee have attended to their duty. They have summoned the Water Commissioners, together with the Superintendent of the Water Works, to appear before them, and have endeavored in every possible way to determine the cause of the increase in the size of the bills presented by the Water Commissioners, which caused considerable adverse criticism by the public at large. . . . The primary cause of the whole trouble we find to be the negligence of an employee of the department, whose duty it was to read the meters. . . . In rectifying the trouble caused by a negligent em-

ployee, the Commissioners used the powers conferred upon them by ordinance and instructed the Superintendent to use his own discretion in settling the bills in a manner as equitable as possible to both parties. The instructions were given to the Superintendent on January 15, 1898, after some abatements had already been made. The committee, therefore, respectfully report that the primary cause of the large bills for 1897 was the negligence of an employee of the Water Department, and it seems surprising to the committee that the employee in question should cause so much trouble without the knowledge of the Commissioners or Superintendent. The administration of the affairs of the department are under the direct supervision and control of the Water Commissioners. They have an indisputable right to make abatements, but the committee seriously question the methods employed. If a consumer used a certain amount of water, and there is no doubt as to the correctness of the meter, he should pay for it. If abatements are to be made they should be made by some established rule. It seems to the committee that some plan ought to be devised which will prevent a repetition of similar occurrences. A careful perusal of the communication of the Superintendent is recommended.

(Signed) JOINT STANDING COMMITTEE ON WATER."

This report was accepted in concurrence by the two branches of the City Government on the same evening.

During 1898, by my direction, the clerk in the office looked over the readings of the various meters at the end of each month, and if in any case there was a consumption larger than the average for that particular service, the following form of letter was sent: —

MR. —— "TAUNTON, MASS., ——

Dear Sir, — Our meter inspector reports that the registration of your meter at —— Street shows a consumption of —— gallons for the month of ——. We send this notice because the consumption is larger than the average monthly use at this place. The department has not the slightest objection, but simply desires to have you aware of the facts, in case there might be leaks or other wastes going on without your knowledge.

Please read the enclosed circular.

Yours truly, GEORGE F. CHACE,
Clerk and Superintendent."

The circular referred to was as follows: —

"WATER RATES.

Notices are sent each month to those consumers the reading of whose meters indicates a larger consumption than usual. This is done simply as an act of courtesy to the consumer, to save him from the expense of paying at the end of the year for undiscovered and prolonged waste of water, arising from any cause. It must be stated with emphasis that, in the experience of this department, large meter bills are *never* due to the fault of the meter. Meters when containing a coating of sediment upon the pistons sometimes register against the consumer, but only to a moderate degree. An occasional error in the reading is easily discovered and always corrects itself. With the above qualification, meters measure the water which goes through them, unless they have become worn and allow water to slip through without registration. If the readings, correctly taken, show a large consumption, it is *not* an indication of 'something wrong with the meter,' but that the water has been used or wasted. No man can guess how much water passes through the fixtures on his premises so accurately as a machine can record. This department is willing to test meters when a consumer distrusts the record, but from long experience the officials of the Water Department know beforehand that meters in the very worst cases will not over-register enough to account for a large bill, and the average of nearly 5,000 tests on record in this office favors the *consumer* and not the Water Department.

GEORGE F. CHACE,
Superintendent Taunton Water Works."

At the next annual collection of meter rates, January, 1899, I made a table of the parties with whom we had trouble in January, 1898, with the amount of settlement in each case and the corresponding bill in 1899. I then looked up the tests of such of the meters in the several cases as had been recently tested, and caused tests to be made of those of which there was not a satisfactory record. I was then ready for business.

Instead of the storm of the previous year, I had only the stiff gale which usually blows on such occasions, and I was much relieved when the crisis was over.

DISCUSSION.

Mr. J. C. Gilbert. I think we can all sympathize with our brother in his experiences in the collection of meter rates. I would like to mention a little experience I have had this last season. You will all remember that the years 1897 and 1898 were what we call wet years, and that consequently consumers did n't use nearly the amount of water which they use in dryer years. But when we made out our bills last July we found that they ran very large, more than double the usual amount. The Superintendent and I had a consultation, went over all the large bills, and then examined the meters personally, and found that they read correctly.

We knew that there was a storm coming, and we made all the preparations for it possible; yet we hardly realized with how much force it was coming. Many of the people declared that they knew a great deal more about how much water they had used than we did. Of course we had prepared ourselves for it as much as we could, and I put on as smiling a face as possible, although I never really felt that I could do what I heard Mr. Haskell once say he did — that when a man came into his office to pay a bill and was dissatisfied, he did n't feel that he had really done his duty unless he sent him away with a smiling countenance. I really never had the faculty to do that in all cases.

Well, at this time I did my level best to explain matters satisfactorily. There were cases where bills which were usually only two or three dollars ran up to ten, twelve, and fifteen, and the men would know that something must be wrong. After a while I made up my mind I would n't have any further discussion, but if a man came in and found fault I would let him have his say, and then if he did n't see fit to pay his bill I would let it stand to see if he would n't cool off. Some men, on the other hand, knew they had used large quantities of water, and they expected to pay for it. It pleased them, and soon in all public places, men were joking each other about their water bills.

We finally told some of those who complained that we would do this: we would take out the meter and test it, and if it over-registered we would discount it, but if it was the other way they should pay the difference. But there was n't one of them who dared agree to that, and the storm finally abated. We thought at one time that there would be an investigation, which we were all ready for, but it

passed over, and the most of the bills have been paid. A number of the largest consumers have held off up to this time, but I think they will all come into the fold before long.

I know that the tests which we have made, like Mr. Chace's, have shown that the trouble was not in the meters. When a man comes in and says he knows he has n't used as much water as he used last year, he is talking about something he really does n't know anything about. As I have said many times, what is the use of having a meter if a man knows just how much water he uses each quarter? One thing we did tell those who complained was that if at the end of October, when we came to take the readings, the meters continued to register high, we would look into the matter further; but the October bills were as a rule very small. Those people who had used the most water before used the least during the succeeding quarter, so that everybody at the present time seems to be pretty well satisfied. I think this is a subject we are all interested in, and I will say for the benefit of the gentlemen here who sell meters that I thoroughly believe in them, and I don't believe the consumer gets cheated. If a meter does over-register it will be such a small amount that it never will do any one any harm.

THE GLASGOW WATER WORKS.

BY JAMES M. GALE, ENGINEER IN CHIEF, GLASGOW WATER WORKS.

[*Read December 13, 1899.*]

The district from which Glasgow is supplied with water lies on the borders of the Perthshire Highlands, about thirty-three miles north from the city. It forms one of the sources of the river Teith, a tributary of the river Forth, which takes its rise in the hills near the top of Loch Lomond, and flows eastward by Stirling and Alloa to the Firth of Forth. The district embraces a chain of three lochs, of which Loch Katrine is the highest, Loch Achray comes next, and Loch Vennachar last, or lowest. Besides these there is Loch Drunkie, a small loch lying on the south side of Loch Vennachar, and flowing into it. Loch Katrine is alone used for the supply to the city; Loch Achray is not used at all; and Loch Vennachar, with its subsidiary loch, Loch Drunkie, is used for supplying the compensation water to the river Teith.

Loch Katrine lies at an elevation of 373 feet above the mean level of the sea, and the hills around it rise to a considerable height; those on the west and north of the watershed rise to 2,524 and 2,839 feet, while Ben Venue, on the southeast, rises to 2,393 feet. The result of this, and of the proximity of the district to the west coast of Scotland which first receives the moist winds from the Atlantic, is a very considerable rainfall. (See Rainfall Observations, Appendix II.)

The area draining into Loch Katrine is 23,192 acres, or about 36 square miles, and the area of the loch itself is 3,150 acres, or about 5 square miles, and over this area power has been given to draw 12 feet vertical of water, which gives a storage capacity of 9,849,-000,000 gallons,* equal to 18.719 inches of rainfall over the drainage area. In estimating the quantity of water this amount of storage would yield for the city, the summer of longest drought since 1853 was taken, that being the date when rain gages were first planted

*The gallons used in this paper are British Imperial gallons, equal to 1.2003 U. S. gallons.

in this district. The longest drought, calculated from the quantity of water which flowed off the ground, proved to be that of 1869, and from the gagings then taken it was found that 65,000,000 gallons per day could be depended upon for the use of Glasgow, and 5,000,000 gallons of compensation water in supplement of the quantity to be discharged from Loch Vennachar down the river Teith — in all 70,000,000 gallons per day. This rate of supply will absorb 48.5 inches of rainfall, and the number of days' supply provided by the storage is 141.

Loch Vennachar, which supplies the compensation water, is at an elevation of 269 feet above the sea. The drainage area tributary to this loch is 23,186 acres, almost exactly the same as that of Loch Katrine, making a total drainage area of about 72 square miles. The area of the water surface of Loch Vennachar is 1,025 acres, and of Loch Drunkie, 138 acres — together 1,163 acres, or nearly 2 square miles. The power to draw water from Loch Vennachar is restricted to a vertical depth of 11 feet 9 inches, which gives a storage capacity of 2,589,000,000 gallons. Loch Drunkie has been raised 25 feet by an embankment, affording additional storage to the extent of 774,000,000 gallons. The quantity of water to be sent down the river Teith is 42,000,000 gallons per day.

The works at the outlet of Loch Vennachar consist of a masonry dam and a new channel for the river, 2,100 feet long and 50 feet wide. The water is discharged by eleven arched openings, with sluices placed at different levels, four of which form fish passes. The top of the dam is roofed in and forms a sluice house for protecting the working gearing of the sluices. In continuation of the dam is a waste weir, 150 feet wide, over which the floods pass, sometimes in large volume.

The geological formation of the district which furnishes the water is the Silurian, which forms all the hills in the West Highlands, including Ben Lomond, Ben Ledi, Ben More, and Ben Vorlich. These hills are precipitous, very hard, almost insoluble, and yield water of the very purest quality. It is altogether a wild, mountainous district, with no cultivated land, and sparsely inhabited, there being not more than a dozen houses within the watershed of Loch Katrine. Heather there is in abundance, but there are few extensive mosses. Loch Katrine itself is very deep — soundings have been got at a depth of 79 fathoms, or 474 feet — which has the effect of retaining the rainfall for more than two years, and

thus affording ample time for subsidence and clarification. The water is very uniform in temperature, the lowest during the winter being 38°.1 at all depths; and 57°.8 at the surface, falling to 45° at greater depths, during summer. The loch does not freeze during winter except at the shallow parts, while in summer the surface water is continually being mixed with the colder water from the greater depths, thus giving a supply of cool water in summer and of relatively warm water in winter. From observations by Dr. John Murray, F.R.S., with the tow-net, the number of minute organisms found in the deep Loch Katrine water are very much less, both in species and individuals, than in the shallow lochs in the vicinity, which have a higher temperature in summer.

To preserve the high quality of the water, various agreements were made with the proprietors of the lands around the loch and confirmed by Act of Parliament in 1892, whereby they are prohibited from erecting any dwelling or other houses within the watershed; and regulating the discharge from all existing houses, and of all steam and other boats on the loch, all of which matters are placed under the control of the Town Council of Glasgow.

Such is a brief description of the district from which the water supply to Glasgow is drawn, and such are the means taken to secure it. The genius of Scott has thrown a never-fading romance around its beauties in "The Lady of the Lake."

Let us now turn to Glasgow itself. It was in 1852, or forty-seven years ago, that the Town Council of the city of Glasgow resolved to have the water supply in their own hands. At that time the population was 360,000, and they were supplied by two water companies — one, the Glasgow Water Company, which pumped its supply of water from the river Clyde, about three miles above Glasgow; and the other, the Gorbals Water Company, which drew its supply by gravitation from a small stream called the Broek Burn, about six miles from Glasgow on the south side of the river. The quantity of water supplied by the two companies was about 14,000,000 gallons per day, or nearly 40 gallons (48 U. S. gallons) per head of the population. But the river Clyde had long ceased to be a proper source of supply. During floods it was much discolored with clay, which what filters the company had were quite unable to remove, and the water was polluted by the towns and villages which drained into it in the upper parts of the river. Both companies were bought

up by the corporation for annuities of £16,167 6*s.* 0*d.* (about $78,680) for the proprietors of the Glasgow Company, and £10,800 (about $52,560) for those of the Gorbals Company, which amounts form a perpetual charge upon the rates of the city. Upon the completion of the Loch Katrine Water Works, the works of the Glasgow Company were abandoned, so that they do not concern us further, but those of the Gorbals Company continue to supply about 1,500,000 gallons per day of very good water to the city, so that a short description of the works is necessary.

The drainage area extends to 2,560 acres, and is entirely of trap which yields very fine water. The water generally has five or six grains of solids per Imperial gallon and has a hardness of 3.°2 on Dr. Clark's scale. The company constructed three reservoirs upon this drainage area, having a capacity of 169,000,000 gallons, and two ranges of filter beds, having a united surface of 1.62 acres. The filters discharge into two clear water tanks of 5,125,000 gallons capacity, from which the water is conveyed to the city by a 24-inch main.

The first Loch Katrine works were completed in the early part of 1860. They included the works at Loch Vennachar and Loch Drunkie, which have not subsequently been altered, and a masonry dam across the outlet of Loch Katrine whereby a command over a depth of 7 feet of water was obtained. This dam had two fish passes and a waste weir, 100 feet wide, in continuation of the dam. The aqueduct, which was intended to convey 50,000,000 gallons per day and which begins about five miles up from the outlet, is 25.38 miles long, is 8 feet wide and 8 feet high, with a semicircular top, and has a fall of 10 inches per mile, or one in 6,336. The aqueduct commences by a basin, in which there are sluices to regulate the discharge of the water, and strainers to keep out fish and leaves, and it terminates in the Mugdock Service Reservoir about seven miles from Glasgow, and at an elevation of 319 feet above the sea. On the aqueduct there are 70 distinct tunnels, upon which 44 vertical shafts were sunk to facilitate the driving. There are five extensive iron bridges of an aggregate length of 2,907 feet, and 20 masonry bridges over ravines and rivers, some 60 and 80 feet in height, with arches of 30 feet, 50 feet, and 90 feet span. At all the bridges overflow and discharge valves are provided. There are three valleys on the line which required to be crossed by siphon pipes with a total length of 3.61 miles. There are three lines of siphon pipes, two 48 inches and one 36 inches in diameter.

At the Mugdock Reservoir the water is discharged from the aqueduct into a basin with gage plates attached, where the quantity is gaged and computed. The reservoir has a water surface of 60 acres, a depth when full of 50 feet, and contains 548,000,000 gallons. From this reservoir the water passes into a well, where it is again strained — for there is no filtration — and from the straining well it enters four cast-iron pipes, each 36 inches in diameter, which convey it to the city.

The total cost of these works up to May, 1882, including Parliamentary expenses, engineering, land, and distribution in the city and adjoining districts, was £1,295,622 (about $6,305,000).

The first Loch Katrine works were completed in 1860, and only a few years had elapsed before it was found that the aqueduct would not discharge the 50,000,000 gallons per day which were expected from it. Darcy and Bazin's *Récherches Hydrauliques* was published in 1865, in which it was proved that the nature of the surface of the channel had a controlling effect upon the quantity of water discharged; and as the aqueduct was not lined where the rocks were sufficiently hard to stand the action of the water, a greater retardation of the flow at these places was produced. In fact, the aqueduct would not discharge more than 12,000,000 gallons per day, and as it was not possible to stop the flow at the loch a sufficiently long time to widen the tunnels or to line them, an extensive new series of works was resolved upon.

In 1885 the population supplied with water had increased to 782,600.* and it was resolved to apply to Parliament for increased powers. A new aqueduct was the most pressing piece of work required, and as it was also the most expensive part of a new scheme, it was resolved to duplicate all the works and to design them for an ultimate supply of 100,000,000 gallons per day. The resources of Loch Katrine were not exhausted by withdrawing 50,000,000 gallons per day from it, and the storage was accordingly increased from a depth of 7 feet to a depth of 12 feet, and the quantity of water for the supply of the city increased to 65,000,000 gallons per day, as described in the early part of the paper, while from the adjoining lochs additional water can be got when wanted. Loch Katrine is the lowest in level of the whole series of lochs, including Loch Arklet, Loch Doin, and Loch Voil, so that the additional water can be discharged into it.

* See table of population supplied with water, Appendix 1.

The raising of the level of the loch this additional 5 feet involved the construction of a new dam at the outlet, which dam will have eleven arched openings, with sluices at varying levels for the discharge of flood water and for fish passes, and a waste weir 70 feet wide. Some miles of new road were also required.

The works authorized by the Act of 1885 consisted, besides the raising of the loch, of a new aqueduct following nearly the line of the old one, but with some important deviations; a new service reservoir; and additional lines of mains from the new reservoir to the city.

These works presented the unusual feature that their construction could be spread over a lengthened period of time. The portions of the aqueduct which offered the greatest obstruction to the flow were first duplicated; the storage at the lochs, the laying of the cast-iron pipes across the valleys, and between the reservoir and the city, could all be carried on from time to time as the demand for water increased; and special powers were asked and obtained from Parliament to carry this proposal into effect.

The new aqueduct begins at the loch in a masonry basin, adjoining the present basin, with strainers fixed in it, and the present one will be raised in level to suit the raised level of the loch.

In designing the new aqueduct, the best kind of bridge for carrying the water channel across the ravines on the line, especially those in the vicinity of Coulegarton and the Duchray water, had again to be considered. The early bridges were formed of cast and wrought iron troughs, and they vary in length from 372 feet to 996 feet, with a total length of 2,907 feet. From being exposed to the atmospheric changes and from the necessity of frequent repainting, they were never considered very satisfactory, and it was resolved not to repeat them in the new aqueduct. By carrying the work almost entirely under ground, these elements of ultimate failure and the crossing of the valley of the Duchray water by siphon pipes would be avoided, and this was accordingly done, though it involved several long tunnels. The new aqueduct consists, therefore, of a series of tunnels; the water is kept at a nearly constant temperature, and the works are more permanent and enduring. At several points connections are made with the old aqueduct, which admitted of the new one being formed in sections and of isolating any section of either aqueduct for repairs.

The tunneling so freely resorted to has the effect of shortening the line by 1.767 miles, and as the total fall reckoned from the lowest level to which the water can be drawn in Loch Katrine to the Mugdock Reservoir is 38.58 feet, a fall of one in 5,500 in the tunnels and one in 960 for the siphon pipes across the valleys of the Endrick and the Blane was obtained. The new aqueduct is intended to discharge 70,000,000 gallons per day, which, with the old one reckoned at 40,000,000 gallons, makes a total of 110,000,000, out of which, and to admit of repairs on the aqueducts, the city is expected to receive a continuous supply of 100,000,000 gallons a day. Where the tunnels are not lined, they are 11 feet wide at the bottom and 12 feet wide at a height of 6 feet above the bottom, and 9 feet high, the top being a segment of a circle. About 50 per cent. of the tunnels had to be lined with concrete, and there they are 9 feet wide at the bottom and 10 feet wide below the springing of the arch. They are all concreted in the bottom with a versed sine of 6 inches. So long as the concrete preserves its smooth surface, the discharge will exceed the calculated quantity of 70,000,000 gallons per day. All the principal tunnels were driven by the aid of compressed air.

The intention of keeping the aqueduct as far as possible under ground has been so far carried out that there are only five short aqueduct bridges on the whole line. These consist of an outer wall faced with granite or whinstone, and an inner wall, with a 4-inch air space between, and an arched top. The whole structure, with the exception of the stone facing, is of concrete.

The Duchray valley has been avoided by the new aqueduct, but there still remained the Endrick valley, 2.425 miles wide, and the Blane valley, 0.675 mile wide, and these are crossed by double lines of cast-iron pipes, 48 inches in diameter. There will ultimately be four lines of pipes, but two were considered sufficient for the present. The thickness of the pipes varied from $1\frac{1}{8}$ inches to $1\frac{5}{8}$ inches, according to the pressure they had to resist. The pipes were each 12 feet long and were cast with plain ends without sockets, and were jointed with steel collars hollowed out $\frac{1}{8}$ inch inside to assist in holding the lead. There have been no burst pipes or leaking joints with these pipes.

Three bridges were required in the Endrick valley — one across a public road, another across a railway, and the third across the river Endrick, the last having a span of 84 feet. They consist

of steel web girders supported on masonry abutments, and are prepared for the additional pipes when required.

The new service reservoir is called the Craigmaddie Reservoir and adjoins the old service reservoir, and is at the same height above the sea. The ground to the east of the old reservoir seemed to afford a convenient site, though the length of the embankment was considerable through its having to be enclosed on two sides in the form of a crescent. Extensive boring operations were carried out on the site, and these disclosed that below the surface covering of peat and sand there existed rock over the whole site. The rock was partly sandstone and partly whinstone. The whinstone, being in flows, was intended to be removed, but it was expected that the sandstone would be watertight, as no difficulty had been experienced in getting a thoroughly satisfactory foundation in the construction of the adjoining Mugdock Reservoir.

The reservoir has a water surface of 88¼ acres with a depth of water available for the city of 40 feet, and at that depth contains 700,000,000 gallons. The embankment is 4,776 feet long, and 93 feet high above the bed of a small stream which flowed through the site; it has a puddle wall in the middle, and slopes of 3 to 1 on the inside and 2 to 1 on the outside in the usual way. Operations were commenced by the diversion of a public road and of the small streams which ran through the middle of the reservoir, and afterwards the excavation of the puddle trench was taken in hand. The sandstone was found to be much shattered by the whinstone which had been forced through it, and the sandstone rested upon a bed of shale, and this bed of shale had to be followed throughout. The trench was 22 feet deep at the end next the Mugdock Reservoir, but it gradually dipped till it was 193 feet deep. After working eighteen months, the first contractors resigned their contract, and the trench was ultimately completed at the cost of the Town Council. The amount of water encountered in the excavation was very considerable, averaging from 400,000 to 450,000 gallons per day for nearly three years, and the greater part of this had to be raised 150 feet.

In the southerly portion of the trench the rock was sufficiently sound to stand without timbering, but towards the north it was much fissured and broken up by faults and required to be timbered. To avoid any risk of the sides of the trench collapsing, large masses of rock were temporarily left in at intervals, and the

excavation carried on by tunneling below them. The trench at this place, for a time, had the appearance of a huge honeycomb.

The total amount of rock excavation in the trench was 168,000 cubic yards, and the total cost was about £90,000 ($438,000), including plant and pumping water. It took six years to complete the excavation, and to enable other portions of the work to be carried on during that time, five concrete pillars were built across the trench as portions of it were cleared to the bottom to allow the puddle filling to proceed. One of the pillars is in the line of a tunnel, formed for the cleansing culvert out of the lowest part of the reservoir; and the pipes laid in it are bedded in the concrete where they cross the trench.

The embankment contains in all 293,760 cubic yards of puddle, 598,750 cubic yards of ordinary earthwork, 44,000 cubic yards of stone facing, and cost about £300,000 ($1,460,000).

The inlet works consist of an aqueduct, 2,862 feet long, to convey 110,000,000 gallons of water per day into the reservoir, this being the capacity of both aqueducts from Loch Katrine, and a connection being made between the old and the new aqueducts so that the flow of either or both can be directed into either reservoir. There is also a gage basin and a measuring pond.

The outlet works, in addition to the cleansing culvert above referred to, consist of a valve tower, a straining well, and a discharge tunnel, 1,260 feet long, in which two 42-inch pipes have been laid for the supply of the city.

In addition to the four 36-inch mains from the Mugdock Reservoir to the city, it is intended that there shall ultimately be four other mains from the Craigmaddie Reservoir, but only two have been laid in the meantime. Five bridges were required in the distance, which is nearly seven miles, three across railways, one across the Allander water, and one across the river Kelvin. The pipes are carried between steel web girders and the masonry abutments are prepared for the two additional lines.

The amount expended on these additional works from May, 1882, to May, 1898, was £1,339,598 (about $6,519,000), including land and all charges as formerly detailed — making the total cost of the water works £2,635,220 (about $12,823,000). The sinking fund now amounts to £896,705 (about $4,364,000), and it is being augmented by £60,000 ($292,000) per annum.

APPENDIX I.

Glasgow Corporation Water Works.

Table showing the population supplied with water, and the consumption per head per day, at intervals of five years: —

April of	Population supplied with water.	Average yearly increase of population.	Average quantity of water supplied per day during whole year.	Consumption per Head per Day.			
				Meter supplies.	Other trade supplies.	Domestic, including municipal purposes.	Total.
			Gallons.	Gallons.	Gallons.	Gallons.	Gallons.
		8,545					
1861	436,901		18,264,864	2.87	2.95	35.99	41.81
		12,856					
1866	501,200		23,737,908	4.57	2.95	39.84	47.36
		18,805					
1871	595,224		29,595,657	5.96	3.60	40.16	49.72
		19,865					
1876	694,548		31,710,844	7.03	4.76	33.86	45.65
		6,031					
1881	724,702		37,329,237	9.43	5.29	36.79	51.51
		14,452					
1886	796,965		40,813,815	9.74	5.48	35.99	51.21
		9,720					
1891	845,564		41,920,698	11.38	6.06	32.13	49.57
		13,687					
1896	914,000		49,157,043	12.49	6.69	34.60	53.78

Note. — Quantities are in Imperial gallons of 277.274 cubic inches, or 1.20032 U. S. gallons.

APPENDIX II.

GLASGOW CORPORATION WATER WORKS.

JAMES M. GALE, Engineer.

RAINFALL in the LOCH KATRINE and GORBALS DISTRICTS, SCOTLAND.

	Among the hills around Loch Katrine.					On the lower ground by Loch Vennachar.						Gorbals District.			
	At Glengyle, head of Loch Katrine. Elevation 380 feet.	On summit of hill above Tunnel at Loch Katrine. Elevation 830 feet.	On hills between Loch Ard and Loch Katrine. Ledard. Elevation 1,500 feet.	At Loch Dhu. Elevation 325 feet.	Head of Duchray Valley. Ben Lomond. Elevation 1,800 feet.	Between Glen Finlas and Ben Ledi. Elevation 1,800 feet.	At Bridge of Turk. Elevation 275 feet.	At Loch Drunkie. Elevation 420 feet.	At Loch Vennachar. Elevation 275 feet.	At the Inn at Aberfoyle. Elevation 60 feet.	At Mugdock Reservoir. Elevation 320 feet.	No. 1. Waulk Glen Reservoir. Elevation 280 feet.	No. 2. Ryat Linn Reservoir. Elevation 310 feet.	At Middleton. Elevation 550 feet.	At Nether Cairn. Black Loch. Elevation 700 feet.
Date when Gages were fixed.	1854	1861	1854	1861	1854	1854	1854	1861	1861	1854	1862	1854	1854	1855	1854
Averages since Gages were fixed, to 1873 inclusive.	Ins. 92.80	Ins. 80.50	Ins. 83.20	Ins. 85.60	Ins. 91.50	Ins. 58.50	Ins. 61.60	Ins. 66.80	Ins. 59.50	Ins. 56.60	Ins. 48.70	Ins. 47.07	Ins. 45.71	Ins. 52.73	Ins. 54.80
1874 . . .	106.60	77.80	55.60	86.50	85.60	50.90	76.00	64.90	58.30	58.60	41.80	48.35	49.30	58.45	62.25
1875 . . .	91.20	77.60	68.70	80.70	80.10	56.80	74.90	67.30	59.40	60.80	47.80	44.95	47.05	54.90	57.80
1876 . . .	93.70	81.80	73.00	82.30	83.80	66.60	74.30	69.00	62.00	56.90	51.40	50.85	53.30	60.10	59.70
1877 . . .	128.50	104.20	87.90	109.10	102.20	78.60	101.00	81.00	79.30	77.00	56.40	62.25	65.55	77.30	77.65
1878 . . .	82.00	65.70	60.80	68.30	64.80	48.40	57.90	51.10	49.70	45.30	38.50	42.10	44.30	51.45	53.20
1879 . . .	87.00	66.60	59.30	67.50	58.80	48.20	57.50	54.60	50.50	49.90	47.70	40.95	45.00	54.90	52.70

1880 . . .	69.00	62.40	50.30	65.00	70.70	40.90	56.70	51.80	45.70	41.40	44.80	38.55	41.00	45.35	55.15
1881 . . .	80.00	71.80	65.70	73.50	74.80	50.20	66.60	64.80	55.40	53.00	47.10	39.00	42.30	43.95	50.20
1882 . . .	104.60	94.60	79.70	97.60	101.30	65.90	86.80	83.40	76.50	71.90	52.30	50.50	55.35	51.60	65.25
1883 . . .	100.60	85.60	67.20	84.90	82.40	55.20	74.50	69.40	67.20	63.80	54.40	49.95	53.80	60.95	63.40
1884 . . .	107.90	89.50	72.00	95.60	95.10	50.70	83.00	75.90	72.30	63.20	59.60	51.80	55.10	62.85	64.90
1885 . . .	84.10	64.50	66.00	79.70	85.60	50.00	69.60	62.30	56.60	53.70	41.90	40.40	40.90	50.50	52.40
1886 . . .	81.10	53.80	59 90	71.80	69.80	47.60	64.70	58.70	54.50	48.60	48.50	44.55	46.25	53.90	54.65
1887 . . .	67.00	41.20	36.70	57.00	61.00	35.10	47.85	46.15	43.30	29.85	36.60	36.90	38.20	44.75	44.60
1888 . . .	89.40	61.90	61.05	75.50	73.60	53.55	62.80	61.65	55.60	56.50	44.95	43.65	44.75	51.00	52.95
1889 . . .	76.30	59.60	47.15	62.50	70.80	38.90	48.35	47.50	43.65	43.95	39.00	38.30	39.50	45.05	48.90
1890 . . .	95.10	82.80	54.75	78.50	84.80	51.50	63.75	65.00	54.90	56.15	53.80	53.05	54.60	59.95	63.55
1891 . . .	94.40	83.60	57.00	82.50	86.40	47.45	65.50	60.90	56.15	57.85	46.88	51.05	52.40	57.10	55.40
1892 . . .	89.60	76.30	57.40	72.30	74.50	47.00	61.75	62.75	55.95	58.60	48.10	49.05	50.20	55.05	59.75
1893 . . .	91.90	81.10	45.95	71.80	72.70	40.10	53.10	53.70	46.40	50.60	43.85	42.95	44.30	47.90	45.95
1894 . . .	101.70	104.30	54.55	86.40	91.10	43.80	69.30	65.50	56.40	64.80	50.55	55.50	56.80	60.60	63.34
1895 . . .	74.20	68.90	47.25	64.10	69.00	40.45	49.60	49.15	45.00	48.95	42.50	38.30	39.50	44.95	42.80
1896 . . .	77.20	73.70	48.35	63.40	68.70	41.30	49.95	51.95	48.05	50.90	43.55	46.45	47.85	53.95	54.70
1897 —															
January .	1.70	2.50	1.30	1.90	1.80	0.90	1.80	1.45	1.70	2.05	2.15	2.45	2.55	2.75	1.90
February	10.10	8.70	5.00	6.90	8.50	2.95	5.35	6.30	4.50	6.00	3.95	4.35	4.50	5.15	4.70
March .	12.50	12.40	6.10	10.20	10.50	5.00	8.60	8.40	7.20	8 55	5.60	5.75	5.90	7.05	5.50
April . .	7.50	5.70	3.55	5.90	6.00	2.60	4.40	3.75	3.30	3.60	2.20	3.10	3.20	3.45	3.00
May . .	3.50	4.00	2.75	4.00	4.50	2.50	3.05	3.60	3.00	2.65	2.50	3.10	3.20	3.90	3.40
June . .	7.80	6.50	7.35	7.00	7.10	6.30	6.15	7.50	6.70	6.90	6.90	6.35	6.50	7.80	8.10
July . .	7.10	4.60	4.45	4.50	4.80	2.80	3.80	3.80	2.70	3.25	2.75	3.05	3.15	3.95	4.10
August .	12.20	11.50	10.70	12.00	12.30	8.50	9.60	9.80	8.10	8.75	6.70	6.25	6.45	7.90	9.10
September	6.10	5.90	4.45	5.20	6 30	3.00	3.90	4.00	3.80	3.90	4.40	3.75	3.85	4.30	4.50
October	6.60	6.40	4.05	5.40	6.10	2.80	3.55	3.40	2.80	3.45	2.45	2.45	2.55	2 85	2.70
November	6.40	7.10	5.35	6.50	7.50	3.20	5.70	6.20	5.15	5.60	3.90	4.80	4.90	5.60	5.70
December	14.60	11.60	5.10	10.50	10.80	5.00	8.60	9.20	7.00	8.20	7.10	7.70	7.90	9.00	7.90
Totals (1897) .	96.10	86.90	60.15	80.00	86.20	45.55	64.50	67.40	55.95	62.90	50.60	53.10	54.65	63.70	60.60
Averages, 1874-1897, inclusive.	90.38	75.68	59.85	77.35	78.90	66.45	65.83	61.91	56.20	55.21	47.19	46.35	48.41	54.60	56.74

COVERED RESERVOIRS AND THEIR DESIGN.

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[*Presented December 13, 1899.*]

The use of covered masonry reservoirs for the storage and distribution of underground water is becoming so general, wherever the elevation and local conditions admit, that a brief consideration of the reservoirs of this class which have been built, a study of the elements which enter into the design, and an investigation of the cost of various sizes and depths of such reservoirs can hardly fail to be of interest.

Standpipes, tanks, or metal structures of any description, although used for the same purpose as earth or masonry reservoirs, are of a nature so essentially different that further reference to them is unnecessary in this paper. The covered reservoir is in the line of natural evolution from the open distributing reservoir, to meet the requirement of exclusion of light from underground or filtered water, although the necessity of providing a roof or covering of some kind leads to a different disposition of materials.

Some Existing Reservoirs.

In referring to reservoirs that have been built no attempt will be made to treat the subject exhaustively, nor to go to ancient history for examples. A few prominent types will be very briefly described.

ENGLISH RESERVOIRS.

In the Proceedings of the Institution of Civil Engineers, Vol. LXXIII, in the year 1883, Mr. William Morris describes a number of covered reservoirs built in England. In the discussion that follows several others are described. Among them is nearly every type of roof covering that has since been built in this country. The arches of these roofs were all of the segmental barrel form. Their spans were from 7 to 17 feet in the clear, their rise from one-eighth to one-third of the span. In the earlier examples the arches were sprung from wrought iron girders, these in turn being supported by cast iron pillars. In later construction brick piers were substituted for the pillars, and later still brick lintel arches springing

from brick piers supported the main arches. No groined arches were included among these examples of reservoir vaulting. Although concrete is employed extensively in the construction of the reservoirs, it is used in the covering arches in only two instances. Except for the spandrel filling, they are of brick in the others. In the cases where concrete was used the clear spans were 12 feet, and the rise $2\frac{1}{2}$ feet in both. In one it was 9 inches thick at the crown and 18 at the skewback, in the other 10 and 20 inches respectively. But two of these reservoirs were circular in plan, the others being square or rectangular. In one of the circular ones the covering arches were concentric, and were supported on rings made of 12-inch iron I-beams resting upon brick piers. The other round reservoir had a vaulting of unique design. It was 64 feet in diameter, constructed with nine radial arches springing from 12-inch I-beams, which rest upon a large cast iron column in the center and upon the outer walls. The iron girders have a slope of 4 feet from the center to the wall. The arches have a span of 22 feet and a rise of 4 feet at the wall; the crown is level, while the span and rise diminish to nothing at the center. The thickness of nearly all of the arches was about 8 inches, or two rings of brick laid on edge.

The side walls were generally rather heavy. In one reservoir they were very light. These were of brick 14 inches thick, built in the form of vertical arches, with 10-foot span and a very slight rise. There was a brick buttress or pier at the springing of each arch. This form being designed to resist the pressure from the outside, it is evident that the inside pressure of the water was supported by the earth backing. These reservoirs are described in detail in the paper, and are illustrated by plates. English practice of that date is quite fully described in the paper and the discussion that follows.

FRENCH RESERVOIRS.

In a paper published in the *Journal of the N. E. Water Works Association* for September, 1888, Mr. Charles H. Swan describes some very interesting covered reservoirs in France. The following extract from his paper refers to one of the most striking features of the reservoir of Menilmontant: "The reservoir is covered by groined arches composed of two courses of bricks laid flat in cement. They rest upon pillars 60 centimeters (2 feet) square and 6 meters (20 feet) between centers. . . . The brick arches are about 8 centimeters ($3\frac{1}{4}$ inches) in thickness, including the plaster-

ing. They were covered by a layer of earth and turf 40 centimeters (16 inches) thick."

AMERICAN RESERVOIRS.

There are at present a number of covered reservoirs in this country. The following is a brief description of several of these:

Newton Reservoir.

One of the earliest of these was built for the water works of the city of Newton, Mass., in 1890 and 1891. It was designed and built by Mr. Albert F. Noyes, city engineer. It is about 125 feet wide by 175 feet long and 15 feet deep. The walls are of rubble masonry, laid in Rosendale cement mortar, about 7½ feet thick at the bottom and 2½ feet on top on two sides and 5 feet on the other two. The covering is of brick arches 4 inches thick, with a clear span of 10 feet and about 10 inches rise. The arches are supported by rows of lintel arches of brick, which rest upon brick piers 20 inches square. The top of the arches is filled up level with concrete to a point 4 inches above the crown. Over this is a filling of earth about 2½ feet thick.

Brookline Reservoir.

A covered reservoir was constructed for the water works of Brookline, Mass., in 1892. It is about 92 feet square and 19 feet deep; its construction is similar to that at Newton, except that the walls and piers are heavier. A description of it is given in a paper read by the engineer, Mr. F. F. Forbes, past president of this Association, and published in the *Journal of the N. E. Water Works Association* for March, 1894. These reservoirs are excellent examples of substantial construction.

Franklin Reservoir.

In the year 1891 Mr. F. L. Fuller, civil engineer, built a reservoir of admirable design and economical construction at Franklin, N. H. It is circular in plan, 70 feet in diameter and about 17 feet deep. The walls are of rubble masonry laid in Rosendale cement mortar, and are 5 feet thick at the bottom and 2½ feet at the top. The covering consists of two concentric brick arches and a central dome. The latter is 23 feet in diameter, with a rise of 3.25 feet. The arches have a clear span of 11 feet, and rise 1.50 feet; the thickness of the arches

and dome is 8 inches. They are supported by two rings of lintel arches and the side walls; the piers of the lintels are of brick, 1 foot square and 7 feet apart in the rings. The piers are much smaller for their load and length than it is customary to make them, and are certainly an interesting example of the extent to which ordinary practice can be departed from with success. Mr. Fuller has since built similar ones at Methuen and Winchendon, Mass. A description of this reservoir is given in the *Journal of the N. E. Water Works Association*, 1892, page 82.

Waltham Supply Well.

In the *Journal of the N. E. Water Works Association* for March, 1894, there is an interesting description of the covering of a supply well at Waltham, Mass., by Mr. Frank P. Johnson, civil engineer. There are arches similar to those at Newton and Brookline; these have a clear span of 11.5 feet, rise of 1.92 feet, and are built of one 4-inch ring of brickwork with no concrete filling over them. There is also a circular dome 40 feet in diameter, 7 feet rise, built of what were called Guastavino tiles 1 inch thick; there were three thicknesses of these tiles in the domed covering. They foot at the skew-back on a metal ring, which resists the outward thrust.

Wellesley Reservoir.

During the summer of 1898 the writer constructed some works for an additional supply of water for the town of Wellesley, Mass. The supply is an underground one, which was recommended by Mr. Desmond FitzGerald, past president of this Association, after a thorough investigation of all available sources. A covered reservoir of a capacity of 600,000 gallons was included in his recommendations. Mr. FitzGerald acted as consulting engineer in the design and construction of the works.

In designing the reservoir many types were considered, and it was finally decided to build it circular in plan, with a roof or covering of elliptic groined arches. It was first thought that such arches were not adapted to a circular reservoir, but further study showed that no real difficulties were involved. Designs for several depths were computed, and it was found that a depth of about 15 feet and

diameter of about 80 feet was more economical for the required capacity than a greater depth. The dimensions of the arches and piers finally adopted fixed the inside diameter at 82 feet, and the depth from the floor to the springing line of the arches was made 15 feet. For a capacity of 600,000 gallons the water line is about 0.7 feet above the springing line, and the overflow was fixed at that point. Material for concrete was more available than for rubble masonry, and the walls were therefore built of that; it was also decided to make the roof of concrete, as its cost is much less per yard than

Fig. 1. — Interior of Reservoir showing Groined Arches.

that of brickwork; and with the latter the thickness of the arches could not be made much less; besides this form of arch requires a great deal of cutting of the brick. The centering for concrete costs more, as it must be made tight and smooth; while that for brick can be made with a covering of narrow strips. Brick was chosen for the piers. The dimensions of the parts of the reservoir as designed were as follows: —

Walls 15 feet high from floor to springing line, 2 feet thick for 5 feet below the springing line, 2.67 feet in the next lower 5 feet, 3.33 feet in the lowest section. Piers 15 feet total height, 2 feet square, with a base 2.67 feet square at bottom. Foundations of piers 3.5 feet square, 1 foot deep. Roof arches 12 feet clear span, 2.5 feet rise, 0.5 feet thick at the crown, filled in level over the piers The material of the excavation was a tight, clayey hardpan with very little water in it; the floor was therefore made only 4 inches thick. A steel ring of channel section, weighing 32 pounds per foot, was set in the side walls just above the springing line. The earth filling over the concrete roof was designed as follows: six inches of clean gravel next the concrete for drainage, and to prevent freezing to the concrete: this gravel went over the sides to the springing line, and was drained by several lines of 4-inch vitrified pipe, which discharged at the toe of the embankment. Over the gravel was 1 foot of earth from the excavation and then 6 inches of loam, making a total of 2 feet. The embankments were carried out at the level of the top to a point 7 feet outside of the inside line of the wall, and thence to the natural surface with a slope of 2 to 1.

The construction was executed as designed, with two exceptions. A great many bowlders were found in the excavation; the specifications provided that "the lower part of the wall might be made of these stones if the engineer should so direct, in which case it is probable that the thickness of the wall will be increased." This was done, and the wall made 4 feet thick at the bottom, or 8 inches thicker than designed, as shown in the folded plate. It was thought that it would not be possible to make as strong work with these bowlders as with concrete. The smooth, rounded stones were split, the rubble laid against forms and so carefully bedded in the mortar that the writer is of the opinion that it would have been perfectly safe to have used the thickness designed. The other change was in the thickness of the earth covering. There being a surplus of loam, it was put on 1 foot thick, instead of 6 inches. This made the total thickness of the earth 2½ feet at the walls and 3 feet at the center.

Portland cement was used throughout. That in the walls was the Brooks-Shoobridge brand; the vaulting was of Alsen, with the exception of about one hundred barrels of Atlas that was used because the Alsen could not be had in time. The concrete made of the Atlas seemed quite as good as the other. The number of parts of sand used to one part of cement were as follows: in rubble

masonry $2\frac{1}{2}$, in the concrete in the walls 3, in the vaulting $2\frac{1}{2}$. The proportion of screened gravel used in the concrete was such that the voids were slightly overfilled. It required approximately 1.1 barrels of cement per cubic yard for the rubble masonry, 1.2 barrels for the concrete with three parts, and 1.3 for that with $2\frac{1}{2}$ parts of sand. These figures are based upon the total amount of each kind of work and the number of barrels used in that work.

A ring made of channel iron, weighing 32 pounds per foot, was set in the side walls, with its bottom at the springing line of the roof arches. The bottom of the reservoir is covered with a floor of concrete 4 inches thick. This floor and the side walls are finished with two coats of plaster; one about $\frac{1}{2}$ inch thick, of mortar mixed in the proportion of 2 of sand and 1 of cement; this coat was leveled up, but not smoothed. The second coat was of neat cement, about $\frac{1}{8}$ of an inch thick, thoroughly rubbed in and smoothed with trowels. There were a few places where the walls were moist from the pressure of the water on the outside, and some trouble was anticipated in making good work with the plastering; but very little was realized, and the work was in excellent condition when the reservoir was filled. The roof was not absolutely tight, and a very heavy rain coming on just as the plastering of a part of the floor was finished, there was some dropping of water in several places, which cut through the $\frac{1}{8}$-inch coat before it was hard and threw off a number of flakes. This made it necessary to plaster over a small portion of the floor. Twelve hours more of setting before the rain would have prevented this; the expense was, however, but a few dollars.

The centering for a roof of this type is an important and expensive factor in the work. Plans were made for centers that would each cover the space between four piers. The contractor believed that it would be better to reduce the size of the single centers, and, as he was not required to adopt the plans of the engineer if his own were satisfactory, he was allowed to use the smaller ones. The writer believes that the extra fitting caused by this change made the total cost of the centering much more than it would have been if the original plans had been followed. Whether this is so or not, the cost of the centers (if used but once), of the supporting timbers and the labor of erection and removal was about $22\frac{1}{2}$ cents per square foot for the inside area of the reservoir. The contractor's plan was to supply centers for one quarter section of the reservoir only, and put the roof on in such sections. This was assented to by

COMMONWEALTH OF MASSACHUSETTS.

State Board of Health.

WATER ANALYSIS.

PARTS IN 100,000.

WELLESLEY

NEW COVERED RESERVOIR.

	No.	Date of Collection.	APPEARANCE.			ODOR.		Residue on Evaporation.	AMMONIA.		Chlorine.	NITROGEN AS		Oxygen Consumed.	Hardness.	Iron.
			Turbidity.	Sediment.	Color.	Cold.	Hot.		Free.	Albuminoid.		Nitrates.	Nitrites.			
Water Not in Use	21741	1898 Jan. 3	Slight	Slight	.03	Faintly Mouldy	Distinctly Mouldy	10.20	.0428	.0186	.71	.2650	.0002	.12	4.3	.0020
	21917	Jan. 19	Slight	Slight	.05	None	None	12.10	.0762	.0344	.73	.2400	.0001	.24	3.8	.0010
	22096	Feb. 7	Slight	Slight	.05	None	None	10.30	.0040	.0076	.70	.1850	.0003	.06	3.9	.0020
In Use	22786	April 11	None	None	.01	None	None	6.90	.0002	.0014	.57	.0830	.0000	.02	3.4	.0060
	26037	1899 Jan. 25	None	None	.00	None	None	6.50	.0014	.0042	.56	.0840	.0000	.01	3.1	.0010

The color of water is expressed by numbers which increase with the amount of color. Boston water, as drawn from a tap at the State House, had an average color in 1898 of 0.41. Other water supplies in the State had an average color of from 0 to 1.39.

All waters containing suspended matter, excepting ground waters, which contain a large quantity of iron, are filtered through filter paper before determining the color and residue on evaporation.

the engineer, with the provision that the heads of the piers should be thoroughly braced in each direction to the outside walls, and that if it was found necessary to have more centers in order to prevent delay they should be provided. Although a large saving in cost of centers would be made in this way, it is a mistaken policy, as it afterwards proved to be in this case. While it is quite possible to do the work in this way if the piers are braced and kept braced, there is a possibility that the braces may be removed without the knowledge of those who realize the danger of their removal, as happened here. When one half of the reservoir had been arched over, one quarter at a time, and the centers were being set for the third section, the center row of piers, or those supporting the outer edge of the finished half of the roof, were overturned, and the arches between them and the next row fell, killing one man, breaking the leg of another, and slightly injuring two more. It was just after seven o'clock, and neither the contractor nor the inspector was present. It was found upon investigation that three or, as two of the carpenters testified, four out of five braces that resisted the thrust on this row of piers had been removed. It transpired afterwards that the braces had been removed from the first section in the same way, and the tensile strength of the concrete was sufficient to keep the arches intact. There was a greater load on the half section, as a portion of the covering had been put on.

With the exception of this unfortunate accident, the work on the reservoir was very successfully carried out. The contractor, Mr. Donato Cuozzo, took a great personal interest in having the character of the work of the very best, and used every effort to make it so. When finished the reservoir was filled and allowed to stand for some weeks without any draft from it; there was practically no loss of water from it. The effect upon the water, as shown by a chemical analysis, of standing without change in this new reservoir was marked. The cause of this has never been explained. The results of the analyses on the preceding page (made by the State Board of Health) show in what way it was affected.

A plan and section of this reservoir is shown in the first folded plate.

The reservoir has now been in use about fifteen months with satisfactory results. The final quantities, their contract price, and the total cost of the reservoir, aside from any expense caused by the accident, are given below: —

3446.20 cubic yards	earth excavation	@	$0.40	$1,378.48
24.50 ,, ,,	rock ,,	@	2.50	61.25
309.80 ,, ,,	rubble masonry	@	3.10	960.38
502.86 ,, ,,	concrete ,,	@	3.50	1,760.01
61.22 ,, ,,	brick ,,	@	10.50	642.00
143.30 ,, ,,	gravel	@	1.00	143.30
484.50 square ,,	plastering wall	@	.20	96.90
570.30 ,, ,,	,, floor	@	.20	114.06
438.60 cubic ,,	loam in place	@	.20	87.72
Setting pipes, gates, etc.				100.00
Seeding and sodding				60.00
148 feet vitrified pipe		@	.25	37.00
Channel iron ring				350.00
Bracing, sheeting, and centers				500.00
Payment to contractor				$6,291.91

In addition to the above there are the following items that were outside of the contract: —

Portland cement	$3,156.18
Cast iron pipe, special castings, gates and gate boxes	464.32
Special ironwork	77.34
Hauling sod	21.38
Gravel in the pit	65.00
Carpenter work on brick house for telemeter	138.93
I-beams for same	24.00
Telemeter transmitter and wiring	70.80
Blacksmith work	15.00
Sodding not done the first season, about	90.00
Total of extra items	$4,122.95
Total cost	$10,414.86

The Design of Covered Reservoirs and Water Filters.

The controlling factors in the design of covered reservoirs for water or sewage and in that of the structure that contains the filtering materials or the filter bed in a water filter of the "sand filtration type," where the latter must be covered, are so similar that the design of both can very well be treated in the same paper. The following discussion of such design is intended to refer to both in so far as it relates to their common features. It will be readily perceived when the discussion refers to considerations peculiar to only one of the subjects, as, for instance, that in regard to the economic ratio of depth to area, which refers only to the reservoirs. For convenience, the word reservoir will be used in referring to the subject of the paper.

The required capacity of the proposed reservoir having been

determined, which determination is independent of the design of the reservoir itself, its form is naturally the first question to be considered. If the choice is not restricted by topography or property lines, either the square or circular form would naturally be chosen. Which of these is the more economical may depend upon local conditions, the relation of depth to area, or to other factors in the case. The natural inference is that the circular form would require less materials in its construction. Where land is expensive the square one might be the cheaper. The cost of each type under various conditions will be given in this paper. As the form departs from the square or the circle the cost increases for the same capacity, since the length of the side walls is greater in proportion to the inclosed area; therefore economical design does not permit a departure from these two forms except where it is rendered necessary by the shape of the lot or the topography of the ground.

The relation of depth to area must next be determined; there seems to be nothing to indicate with any certainty what this ratio may be. The amount of excavation is about the same for any ratio; the cost of the roof, floor, and piers will increase directly with increasing area; the cost of the side walls increases about as the square root of the area. On the other hand, an increase in depth involves an increase in the cost of the walls, which is greater than that of their depth, owing to the increasing thickness of the bottom. In an absolutely scientific design the material in the piers will increase faster than their depth, due to the necessity of making their horizontal dimensions greater as their length increases. If not altogether impossible, it would be very difficult to construct a formula that would combine all of these factors and give the economic ratio. An endeavor will be made in this paper to provide a means of ascertaining this ratio for certain types of reservoirs without having recourse to the tedious method of designing and estimating upon several reservoirs of different dimensions. In the discussion of the design of a reservoir the several parts will be treated separately.

ROOF, OR VAULTING.

The design of the vaulting is more independent than that of the other parts, and their design is largely influenced by it; therefore the first consideration will be given to it. This paper is intended to treat wholly of masonry or imperishable construction, and no atten-

tion will be given to roofs of other types, although such may be quite satisfactory under some conditions.

The choice of material for the arches is practically confined to two kinds. Brick is the material of which most of the covering arches have been made. The use of concrete is increasing rapidly at the present time, and, when properly made with Portland cement, it cannot be surpassed. Its cost per cubic yard is about one half that of brick masonry, and it is not necessary to use a greater quantity than of the latter. However, either makes an excellent vaulting, and the choice may often depend upon the local availability of the material. Concrete was used in the arches of the Wellesley reservoir, and in one built by Mr. F. L. Fuller for the State Hospital for Epileptics at Palmer, Mass. The vaulting of the filter beds built by Mr. Allen Hazen at Albany is also of the same material. A sewage reservoir built at Clinton by the Metropolitan Water Board is covered with concrete. As concrete can be placed in any form with little trouble, almost any type of arch may be selected. Consideration must of course be given to the comparative difficulty of making the centers.

Groined elliptic arches offer many advantages: the quantity of the material required is small; there is a clear head room in each direction, which is not the case with barrel arches; and the arrangement is good for ventilation. With groined arches both lintel arches and iron girders are avoided. This type was adopted by Mr. William Wheeler in the composite brick and concrete arches of the filter beds at Ashland, Wis., and Somersworth, N. H. It was also adopted for the concrete arches of the Wellesley and Clinton reservoirs, and by Mr. Hazen for the Albany filters. The dimensions of the arches in the first two instances were as follows: clear span 13.75 feet, rise 3.50 feet, thickness at crown about 5 inches, or the thickness of two bricks laid flatwise. By a curious coincidence, which was the result of independent study, the Wellesley and Albany arches have exactly the same dimensions, — namely, clear span 12 feet, rise 2.50 feet, thickness at the crown 0.50 feet. In the Clinton reservoir the span and rise is the same, and the thickness of the crown is 1 foot. The thickness of the earth covering is about twice as great as in the other cases. This study of design will be limited to elliptical groined arch vaulting, with especial reference to the use of Portland cement concrete.

The determination of the unit pressures is rather uncertain.

When built of concrete, and to a certain extent when built of brick in cement, an arch of this form is monolithic, and a portion of the internal stress is resisted by the tensile strength of the material, instead of being wholly in compression, as in a barrel arch. The stresses, in a section of the arch normal to the axis and in line with the piers, are probably compressive in so far as they are caused by the load upon that section. Since there is no diagonal rib or arch at the groin to carry the pressures caused by the load on the flanks

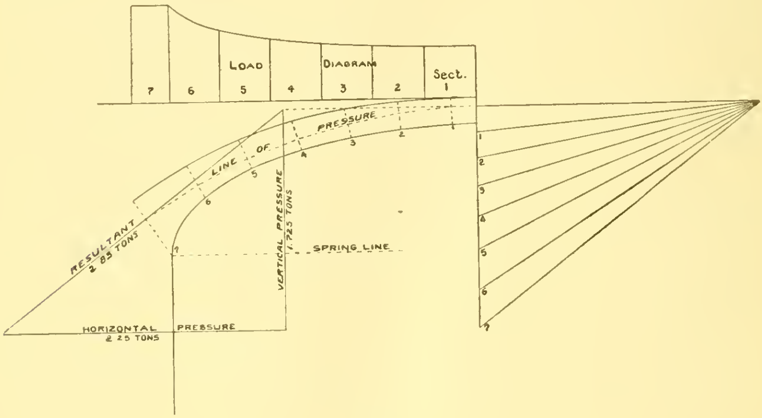


FIG. 2.

of the arches to the piers, these pressures must be distributed by the tensile strength of the material between the normal arch and a certain portion of the groin in a way that would seem to defy mathematical treatment.

It is impossible, however, to secure a bond between new work and that already set, in which the adhesion of the new to the old is equal to the cohesion in the body of the material. In work of much extent such bonding cannot be avoided. Contraction cracks are also quite sure to occur in large areas of masonry. In view of these considerations, it is probably wise to neglect the tensile strength, or at least give but it little weight, and if any consideration is to be given to computed pressures, to calculate them approximately, under the most unfavorable conditions.

The load on the arches is their own weight, that of the earth covering, the water that it holds in saturation, ice and snow, and whatever load of people may come upon it. As a distributing reser-

voir is usually in a sightly place, the last item must be given due weight, unless thorough provision is made to exclude visitors.

Fig. 2 shows a section, normal to its axis, of an arch with a clear span of 12 feet, rise of 2.50 feet, and thickness at crown of 0.50 feet; also a graphical representation of the pressures in a unit section of 1 foot. These dimensions are taken as being identical with those of two recent examples actually built, and, with the exception of the thickness, of one that is being built, and because there seem to be reasons for using about these dimensions. (The latter is opinion only, and cannot be demonstrated except by a great deal of work in designing and computing those of different dimensions and estimating their effect upon other parts of the reservoir.)

Table No. 1 gives the loads, and Table No. 2 gives the unit pressures at the different points of the arch shown in Fig. 2.

Table No. 1.

Loads on Normal Arch.

No. of Section.	Area of Concrete, Sq. Ft.	Wt. of Concrete, Lbs.	Wt. of Earth, Lbs.	Wt. of Snow and Ice, Lbs.	Wt. of People, Lbs.	Total Weight, Lbs.	Total Weight, Tons.
1	0.52	78	250	25	50	403	.202
2	0.60	90	250	25	50	415	.207
3	0.72	108	250	25	50	433	.216
4	0.97	145	250	25	50	470	.235
5	1.34	201	250	25	50	526	.263
6	1.98	297	250	25	50	622	.311
7	2.25	337	187	19	38	581	.290
Total load on one foot section of half-arch							1.724

Table No. 2.

Average Unit Pressures on Normal Arch.

No. of Joint.	Total Pressure on Joint, Tons.	Area of Joint, Sq. Ft.	Average Unit Pressure per Sq. In., Lbs.	Average Unit Pressure per Sq. Ft., Tons.
1	2.26	0.50	62.80	4.52
2	2.29	0.53	60.	4.33
3	2.33	0.56	57.60	4.15
4	2.41	0.59	57.	4.10
5	2.52	0.62	56.	4.03
6	2.67	0.70	53.	3.81
7	2.90	1.33	30.20	2.18
At crown	2.25	0.50	62.50	4.50

As the arch proper and the spandrel filling are one mass, in computing the pressures the extrados of the arch must be assumed. In Fig. 2 a thickness was found by trial in which the unit pressures would nowhere exceed that at the crown, and in which the line of pressure would lie wholly within the middle third. The average unit pressure at the crown is 4.50 tons, and, as the line of pressure at this point is one third of the thickness from the outside, if the material is considered as inelastic the maximum unit pressure will be twice the average, or 9 tons. This is probably the greatest pressure in the arch. The line of pressure is also at one third of the thickness from the soffit near the point called joint 5. At all other points the line of pressure is well within the middle third, and the maximum pressures are less. There seems to be no way in which the unit pressures in the groin can be determined with much precision, as there is no separate rib or arch in which to compute them. If a width is assumed for a rib the pressures in it are modified by the tensile strength of the material of which it is a part; this must prevent the result from being even approximately correct. The unit pressures at and near the groin are probably slightly in excess of those in the normal arch. This opinion is based upon some rough approximations. It is, however, hardly worth while to make elaborate calculations to find these pressures; there are several examples of

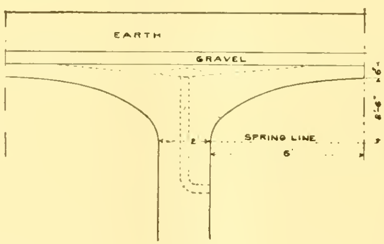


FIG. 3.

this type of arch with a thickness of 6 inches at the crown in actual existence. If it is desired to make a saving in material from that required by this thickness, it will be better to depress the filling over the piers and leave the crown thickness 6 inches. The arches of the Albany filters were made with such a depression; this is shown by the dotted lines in Fig. 3. This depression was filled with clean gravel and drained into the filter by pipes set in the piers. These

pipes are also shown by dotted lines in Fig. 3. Where it is permissible to drain the water that seeps through the earth covering, to the inside, this is in some respects better than a flat surface; some concrete is saved without weakening the arch, and the drainage of the top of the vaulting is freer.

The amount of material in cubic yards in vaulting when constructed as shown in Fig. 3 is given in Diagram No. 1. This is designed to give the quantity within the inside lines of the side walls for different dimensions of square and circular reservoirs (2½ per cent. excess is allowed to cover variations). The cost per cubic yard of concrete in the vaulting is probably no greater than in other parts of the reservoir, if the cost of the centering is not included, but treated as a separate item. The cost of the centers, their supports, and placing and removing them, is from 15 to 20 cents per square foot for the interior surface of the reservoir if it is all centered at once. If it can be centered and covered in sections the cost of centering will be greatly reduced.

EXCAVATION AND EMBANKMENT.

When it is possible to do so, as it usually is in a distributing reservoir, economy demands that the material from the excavation shall be approximately sufficient to make the embankment. For

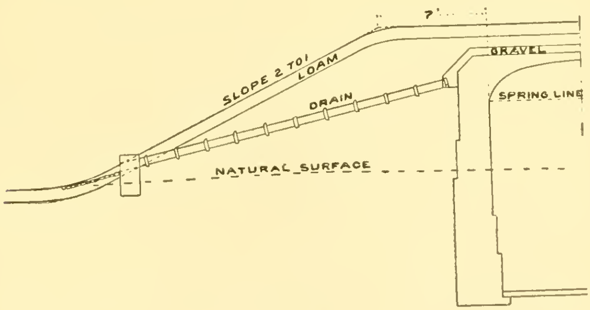


FIG. 4.

ordinary conditions Fig. 4 shows a good design for the embankment of either a square or circular reservoir, or for a filter that is partially in embankment.

Diagram No. 2 gives the quantities of excavation and embank-

ment in square and circular reservoirs of different depths and dimensions.

Trial computations to determine the elevation at which the excavation will balance the embankment are usually tedious. A few minutes' work with Diagram No. 2 will determine this so nearly that one check computation will enable it to be fixed as nearly as it is possible to do. If the site is level the results from the diagram are correct; if it is not level, take the average elevation of the ground to be covered by the reservoir and its banks, and the result will be approximately correct. One exact computation will then show whether it should be raised or lowered a trifle. Ten per cent. is allowed in the diagram for shrinkage. The method of finding the elevation, or, in other words, the depth below the average of the surface, that the bottom of the reservoir should be placed is as follows: After the required horizontal dimension and total depth are determined, find on the lines of the diagram, which represent the diameter of a round reservoir, or the length of side of a square one, a depth of excavation and a height of embankment both of which fall upon the same horizontal line representing quantity in cubic yards, and together equal the total depth of the reservoir from the floor to the water line. *Note.* — When reading quantities in excavation the scale for diameter or length of side must be read at the bottom of the diagram, this scale reading from right to left; while the dimensions must be read at the top when quantities in embankment are required, this scale reading from left to right.

Generally more than one trial will be necessary to find a depth of excavation and height of embankment the sum of which will just equal the total depth of the reservoir, somewhat as follows: If a proposed circular reservoir is to be 100 feet in diameter and 15 feet deep, assume for first trial that the depth of excavation will be 8 feet. Then on the diagram at the left, for round reservoirs, find the intersection of line for 8 feet depth with that of 100 feet diameter; read on the bottom scale. At this intersection the horizontal line has a value of 2,960 cubic yards. Following this line across to the line for 100 feet diameter on scale for embankment, read at the top, we find that value of the curve for embankment intersecting at this point is 6 feet below the water line. Therefore, the total depth of a reservoir that an excavation of 8 feet would provide embankment for is 8 plus 6, or 14 feet; but the required depth is 15 feet, and another trial must be made. Less than 1 foot must be added to

the 8 feet of the first trial. Trying 8.6 feet as nearly as it can be read, following the same process as before, we find 3,160 yards of excavation and a trifle less than 6.5 feet for the embankment below the water line, making a total of practically 15 feet. Owing to the uncertainty in the actual shrinkage of any soil, a determination within one or two tenths of a foot is near enough for practical purposes. The actual amount of the embankment measured in place will, of course, be only 90 per cent. of that read from the diagram, as that includes the 10 per cent. for shrinkage.

N. B. — *Depth of reservoir or "depth" when used in the diagram always means the depth of water from floor to high-water line.*

If the reservoir is located in a hollow, the excavation will be somewhat less than the diagram gives, using the average elevation of the ground. If on a knoll, and probably if on a slope, it will be more. A trial location by the diagram and one check computation will enable the elevation to be fixed. If the reservoir is wholly in excavation, the amount will be found on the diagram by using the depth from the surface to the inside bottom of the reservoir.

SIDE WALLS.

The side walls should be vertical, or nearly so, in order that the vaulting shall have to cover as little area as possible. The ordinary practice in the design of dams or retaining walls is not applicable to these walls. Being supported outside by the earth, they are not like a masonry dam. The thrust of the vaulting resists the tendency of the wall to rotate on its toe; therefore they are unlike retaining walls. If the masonry were homogeneous, the wall of a square or rectangular reservoir would act as a beam, with the roof and floor as supports; but it is improbable that the bonding of the horizontal joints would be sufficiently good to prevent failure. When, however, the point of failure is reached, in order for it to proceed a crack or joint must open on the inside of the wall. If the material is assumed to be rigid, either the part of the wall above the break and the load upon it must be raised or the lower portion must be pressed into the earth with a force equal to the load above to allow the crack to open. In this case the moment of the external forces acting upon the wall is resisted by that of the weight with its lever arm.

An examination of Fig. 5 makes it evident that the whole wall

must be raised, but, as one edge is supported, only one half of its weight resists forces tending to lift it; the weight of the half-arch of the roof with its load must also be raised. If it is assumed that the material is not rigid, but will be crushed or tend to be crushed on the edges on which the two parts rotate, the weight must still be raised; but the lever arm of the weight will be shortened by so much of the thickness of the wall as will sustain the weight above the break without exceeding the strength of the material. In a reservoir that is to be emptied occasionally, the maximum outside pressure on the wall would be that due to water remaining in the earth behind the walls. With a reservoir partly in excavation the

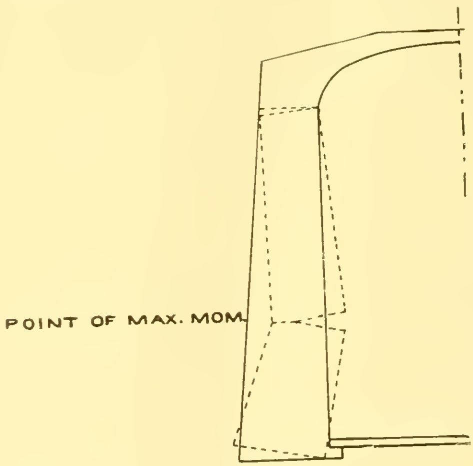


Fig. 5.

height of this water could not exceed the high-water line of that inside, while in one wholly underground it might be at the surface, or even above it, if the site were occasionally flowed. The maximum moment of this pressure, assuming that the water outside is at the springing line of the roof arches, is at one third of the height of the wall from the bottom; its amount in foot-pounds is that due to a load distributed in the form of a triangle, whose base is equal to the height of the wall, and whose altitude is equal to the height in feet into the weight of water per cubic foot.

The foregoing refers to straight walls only; in the walls of round

reservoirs the outside pressure is resisted by the wall as an arch. If this pressure is assumed to be due to the water in the earth backing, it will be uniform all around, and the maximum pressure at any point will not exceed one half the product of the unit pressure by the diameter. The total pressure will increase with the depth and the diameter until dimensions are reached for which the thickness must equal that for straight walls. For greater dimensions they must be designed to meet the conditions of the latter. The thickness of the top of the wall is not governed by these considerations. The thrust of the roof will largely determine this thickness. On straight walls, as shown in Fig. 6, the horizontal thrust of the roof

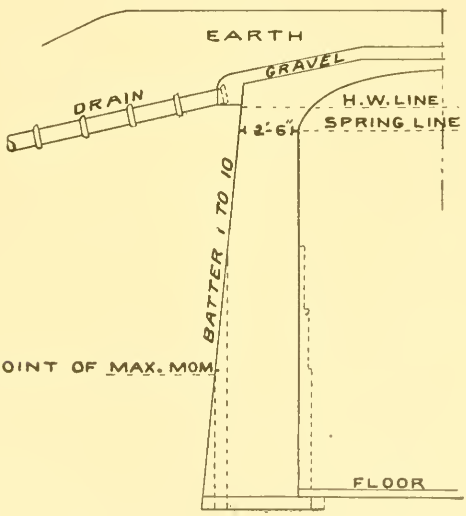


Fig. 6.

is approximately 2.25 tons per lineal foot. Neglecting the adhesion of the mortar, there are two factors of resistance to this thrust, — that caused by the friction of the wall and its load on any joint or place in the wall where movement would take place, and that due to the embankment above such joint. With a thickness at the springing line of $2\frac{1}{2}$ feet, as shown in Fig. 6, the sum of these two elements of resistance, above a point in the wall where the resultant pressure of the arch and the wall above this point passes through the out-

side of the middle third, is about 1.9 times as great as the horizontal thrust of the roof, or there is a factor of safety of nearly two.

With circular walls in which the groined arch must be carried out to the wall at most points and can be at all, the average horizontal thrust is not so great as in straight ones, being about 1.75 tons per lineal foot. The resistance of the embankment above the springing line is about 2 tons, or 1.15 times the thrust. It is easy to increase this resistance by a ring of steel imbedded in the wall above the springing line; therefore it is not necessary to thicken the wall, as the roof exerts only a vertical pressure upon it. Its thickness will then be determined by the requirements of practical construction; all of these will be met by a thickness of 2 feet at the springing line.

The following are examples of existing walls with this type of roof. The first two have straight walls. Those of the filter beds at Ashland, Wis., are 2 feet thick at the top, and have a batter of about 1 in 10. These are either wholly in excavation or have an embankment 15 feet wide, supported by a braced pile trestle. The walls of the Albany filters are in embankment, are 2½ feet thick at the top, and have a batter of 1 in 10. For circular reservoirs, the walls of the Wellesley reservoir are 2 feet thick at the top, and those of the sewage reservoir at Clinton are 2 feet thick at the top and have a batter of 1 in 10.

A steel ring was imbedded in the walls of the two last-named reservoirs. In the Wellesley reservoir, which was 82 feet in diameter, this ring was made of a channel weighing 32 pounds per foot. In the one at Clinton it is in three parts or rings of flat iron. This reservoir is 100 feet in diameter, and the total weight of the rings is 30 pounds per lineal foot. This seems to be a better arrangement of the steel than the channel section, as the joints or splices in the different rings can be "staggered" and the loss of strength in the total section reduced to that in one ring; and it can probably be furnished and placed at a lower price per pound.

Fig. 7 shows the arrangement of such rings in the section of the wall. The following table gives the required weight for reservoirs of various diameters per lineal foot and the total weight. The weights given are designed to provide a factor of safety of three in the resistance to the thrust of the vaulting, including the resistance of the earth embankment. *Note.* — In computing the resistance of the embankment and the wall to sliding a coefficient of friction of 0.80 was taken for earth, and 0.65 for masonry. The weights in the

following table are also given on Diagram No. 1, which will give other diameters than those in the table : —

TABLE No. 3.

Weight of Steel Ring.

Diameter in Feet.	Weight in Lbs., per Lineal Foot.	Total Weight in Lbs.
50	14.5	2,280
60	17.4	3,280
70	20.3	4,460
80	23.3	6,850
90	26.2	7,380
100	29.	9,120
125	36.3	14,300
150	43.5	20,600
175	50.8	28,000
200	58.	36,500

Formula for dimensions not in table: Weight per lineal foot = 0.29 Diam. Total weight = 0.912 Diam.^2

In the above table 25 per cent. is allowed for splicing and rivets; therefore, to find the weight of the net cross-section take 80 per cent. of the above weights per lineal foot.

In the construction of the walls satisfactory results can be secured by the use of either concrete or rubble masonry of sound angular stones of any sizes that are not large enough to go entirely through the wall. Exceedingly good work can be done with small stones by laying the face of the wall up to a form and bedding the stone thoroughly in the mortar without regard to bonding, making a coarse concrete in fact. All smooth, rounded stones should either be broken or thrown out. Portland cement should be used for this work, as it should be for all of the work in such reservoirs. Natural cement may, of course, be used, but as strength is required rather than weight, the cost of equally satisfactory work will be greater than with Portland cement. The choice of concrete or rubble will probably depend upon the kind of material which is the most available.

Diagram No. 3 gives the amount of masonry in the side walls of square and round reservoirs. This diagram is computed from the sections shown in Figs. 6 and 7, and includes all of the masonry from the under side of the foundation to the extreme top of the wall. "Depth," as before, means depth of water. These sections are sufficient for reservoirs of the dimensions given on the diagram.

and are uniform for all. They could perhaps be made lighter for the smaller sizes and depths of the round reservoirs if it was considered desirable to do so. For preliminary estimates it is hardly worth while to make any changes from the quantities given on the diagrams. The following tables give the approximate unit pressures that the maximum outside pressures bring upon the masonry when calculated in the manner already indicated : —

TABLE No. 4.

Straight Walls.

Height of Wall.	Maximum Moment.	Weight of Wall to be Raised.	Necessary Length of Lever Arm.	Thickness of Wall at Point of Max. Moment.	Thickness Remaining to Resist Crushing.	Total Pressure on Masonry.	Max. Unit Pressure Tons per Sq. Ft.
Col. 1	2	3	$4 = \frac{\text{Col. 2}}{\text{Col. 3}}$	5	$6 = \frac{\text{Col. 5}}{\text{Col. 4}}$	7	$8 = \frac{\text{Col. 7}}{\text{Col. 6}}$
5 feet......	0.180	2.62	0.07	2.80	2.73	2.40	0.88
10 ,, ...	1.50	3.24	0.47	3.20	2.73	2.80	1.03
15 ,, ...	4.78	4.10	1.17	3.50	2.33	3.20	1.38
20 ,, ...	11.25	4.80	2.35	3.80	1.45	3.80	2.62
25 ,, ...	22.00	5.60	3.93	4.20	0.27	4.30	16.00

TABLE No. 5.

Circular Walls at Depth of 25 Feet.

Diameter.	Total Pressures at Bottom on Section One Foot High.	Cross-section in Square Feet.	Maximum Unit Pressure per Square Foot.
Col. 1	2	3	$4 = \frac{\text{Col. 3}}{\text{Col. 2}}$
50 feet...........	19.5 tons	4.50	4.33 tons
75 ,, ...	29.6 ..	4.50	6.57 ,,
100 ,, ...	39.05 ,.	4.50	8.67 ,,
125 ,, ...	48.80 ,,	4.50	10.85 ,.
150 ,, ...	58.50 ,,	4.50	13.00 ,,
200 ,, ...	78.00 ,,	4.50	17.35 ,,

Although the extreme pressures in the tables may be considered rather high for rubble and concrete, it must be remembered that they could only occur if the water in the earth backing remains at the high-water line until the reservoir is wholly emptied. This would be a rare condition in an embankment, and may be avoided entirely if desired. The method of doing this will be referred to hereafter.

The pressure of the water in the reservoir tending to force the wall outward must be resisted by the earth backing, otherwise the wall would have to be designed as a dam. If this were necessary, none of such walls that are existing to-day would have stood. If there is

a slight yielding in the earth, it is probably compensated by some elasticity in the masonry. It is of the utmost importance, however, that the backing be deposited in very thin layers and thoroughly rammed. If the nature of the excavation is such that it will stand vertically or nearly so until the wall can be built, it is desirable to make the lower part of the latter without batter or offset on the outside to as high a point as possible and to lay the masonry solidly against the undisturbed earth. If the theory of the resistance of straight walls that is adopted in this paper is correct, they may be built with a vertical back from the point of maximum moment (at

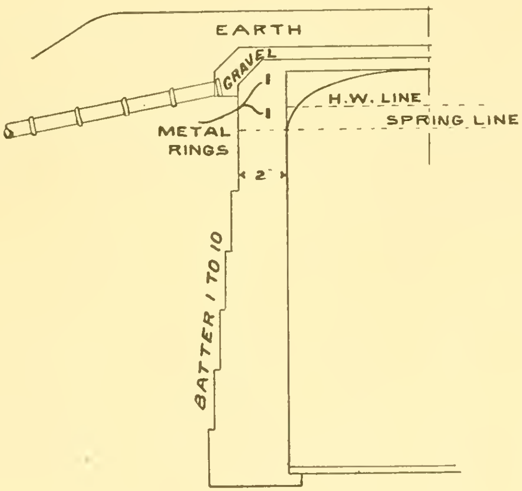


Fig. 7.

one third of their height) to the bottom without loss of strength. Fig. 4 shows how circular walls may be built to secure a vertical line in the lower part of the wall; there will generally be no objection to the interior offsets, and in filters they are desirable in order to avoid a direct line for the water to follow from top to bottom.

There is one more factor to be considered in the design of straight walls; that is, the tendency of the wall to slide into the reservoir. Following the idea that the wall is a loaded beam, the tendency to slide must be met by a reaction at the top equal to one third, and at the bottom equal to two thirds of the total load on the wall. As-

suming water pressure at the back as before, the loads and reactions are as follows:—

TABLE No. 6.

Reactions at Top and Bottom of Straight Walls.

Height of Wall.	Total Load.	Reaction at Top.	Reaction at Bottom.
5 feet..........	0.39 tons	0.13 tons	0.26 tons
10 ,, ...	1.56 ,,	0.52 ,,	1.04 ,,
15 ,, ...	3.50 ,,	1.17 ,,	2.33 ,,
20 ,, ...	6.23 ,,	2.08 ,,	4.15 ,,
25 ,, ...	9.75 ,,	3.25 ,,	6.50 ,,

There are three factors of resistance to sliding at the bottom of a wall such as shown in Fig. 6,—the friction of the wall on the earth, the resistance to compression of the concrete floor, and that of the earth inside of the foundation under the floor. With a floor 4 inches thick and wall foundation 6 inches deep, with coefficient of friction of the wall on the earth of 0.65 and safe pressures on the earth and floor concrete of 2½ and 10 tons per square foot, respectively, the total resistance for a unit section 1 foot long is given in Table No. 7:—

TABLE No. 7.

Resistance to Sliding of the Bottom of Straight Walls.

Height of Wall.	Friction on Earth.	Resistance of Concrete.	Resistance of Earth.	Total Resistance.	Reaction at Bottom.	Excess of Resistance.
5 feet......	1.76	3.33	1.25	6.34	0.26	6.08 tons
10 ,, ...	2.27	3.33	1.25	6.85	1.04	5.81 ,,
15 ,, ...	3.05	3.33	1.25	7.63	2.33	5.30 ,,
20 ,, ...	3.83	3.33	1.25	8.41	4.16	4.25 ,,
25 ,, ...	4.62	3.33	1.25	9.20	6.50	2.70 ,,

These figures indicate that such walls under 25 feet in height will not fail by sliding at the bottom. They will not fail at the top if the thickness is sufficient to prevent shearing. The reaction at the top of a 25-foot wall is 3.25 tons. The section to be sheared in a wall 2½ feet thick at the top is 360 square inches per lineal foot, or a stress of about 19 pounds per square inch will result. There are no data on the shearing strength of concrete; it seems, however, that it must be greater than the tensile strength, and that the above must be a safe figure for that of good concrete or rubble in Portland cement. The above stresses occur only in a reservoir that is just emptied.

Note.—As the thrust of the vaulting against the wall in the proposed design is but 2.25 tons per lineal foot, if the required reaction

at the top must exceed that amount in order to resist the outside pressure, the load on the vaulting must be made heavier and the vaulting stronger to provide the required reaction.

PIERS.

The maximum load upon each pier with the roof shown in Fig. 3 is about 46 tons, the piers being 14 feet apart on centers in each direction. Piers can be built of either brick or concrete. The great majority of existing piers are of brick, very few of concrete being on record. There seem to be practical reasons for the use of brick. The amount of material is not large, and it is probable that the expense of making and setting forms for concrete will make its cost as great in this class of work as that of brick.

The allowable unit pressure for Portland cement brickwork is not definitely determined. Baker, in his book on "Masonry Construction," gives about 30 tons per square foot as a general estimate. In a pier, however, the relative dimensions should be considered in its design. There is a wide diversity in practice, as shown by existing examples. The following table gives the dimensions and unit pressures in several modern reservoirs: —

TABLE NO. 8.

Dimensions of and Pressures on Piers.

	Piers			Roof Surface			Unit Pressure
Reservoir.	Height, Feet.	Section, Square Feet.	Cross-section Divided by the Height.	Area, Square Feet.	Approx. Weight, Tons.	Unit Pressure, Tons.	Multiplied by Length of Pier.
Newton	13.5	2.78	0.205	136	32.	11.5	155
Brookline	17.5	4.00	.228	144	26.5	6.63	116
Franklin...........	16.5	1.00	.061	90.5	20	20.	330
Ashland	5.0	4.00	.80	248	54	13.5	67.5
Wellesley.........	12.25	4.00	.325	196	51	12.75	156
Albany	7.5	2.78	.370	187	41	14.75	111
Clinton	7.0	4.00	.572	210	78	19.5	136
Proposed	7.0	2.78	.398	196	46	16.55	116

The height of piers given in the above table is not in every case the total height from the floor to the springing line, but the length between offsets. The piers in the first three cases had no offsets, but were uniform in size from top to bottom; in all of the others the bases of the piers were enlarged, and in the Clinton reservoir and the proposed design the top is also enlarged by offsets. It is very desirable to spread the base in order to distribute the strains over as

large an area of the top of the foundation as possible, so that it may be made thinner and still not overload the earth below. Where the unit pressures are high it is also desirable to spread the top of the piers, so that they may not be so great in the concrete at the springing line. A neat and economical design for piers has the body of the same size for all heights, and makes the offset portion at the botton (and at the top if desirable) longer as the total length of the pier increases, keeping the length of the body the same for all heights of reservoir.

Fig. 8 shows a pier of this design. The body of the pier is 20 inches square, and for heights of 8.25 feet and over its length is 7 feet. The base increases in height, but not in bottom area, as the pier is made longer. Diagram No. 4 gives the amount of brickwork in such piers for different sizes of round and square reservoirs. These quantities are based upon the areas of the reservoirs, and are not precisely correct for some dimensions, but are nearly enough so for preliminary estimates. The following table gives the exact amount for one pier, and, if closer results are desired than the diagram gives, the exact number of piers can be obtained from a plan and the quantities from the table used : —

Table No. 9.

Brickwork in Piers of Various Heights from Floor to Water Line.

Note. — This height is 1 foot greater than the actual length of the pier.

Height of Reservoir.	Brickwork, Cubic Yds.	Height of Reservoir.	Brickwork, Cubic Yds.	Height of Reservoir.	Brickwork, Cubic Yds.
5 feet	0.62	12 feet	1.62	19 feet	3.01
6 ,,	.72	13 ,,	1.82	20 ,,	3.20
7 ,,	.83	14 ,,	2.03	21 ,,	3.40
8 ,,	.95	15 ,,	2.24	22 ,,	3.60
9 ,,	1.10	16 ,,	2.45	23 ,,	3.79
10 ,,	1.27	17 ,,	2.64	24 ,,	3.98
11 ,,	1.45	18 ,,	2.83	25 ,,	4.17

Piers should be built of the best of brick, in respect to the qualities of hardness, homogeneity, and uniformity of shape and dimensions. They should be laid with absolutely full joints in Portland cement mortar as closely as the brick can be laid, and the joints neatly struck with a jointing tool.

PIER FOUNDATIONS.

Pier foundations should be designed to transmit the pressure from the piers to the earth uniformly, with a unit pressure that is safe for the character of the ground. The following table is taken from Baker's "Masonry Construction": —

TABLE No. 10.

Safe Bearing Power of Soils.

Kind of Material.	Tons per Sq. Ft. Minimum.	Maximum.
Clay in thick beds, always dry	4	6
Clay in thick beds, moderately dry	2	4
Clay soft	1	2
Gravel and coarse sand, well cemented	8	10
Sand, compact and well cemented	4	6
Sand, clean and dry	2	4
Quicksand, alluvial soils, etc.	0.5	1

The soil in most sites of reservoirs for water supplies would be as strong as sand, compact and well cemented, and could be loaded with

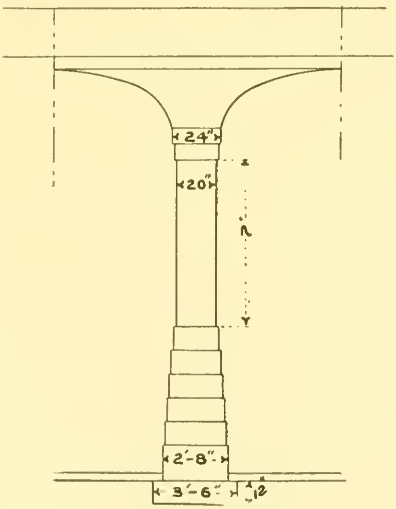


FIG. 8.

4 tons per square foot. Sewage reservoirs and filter beds might often be on less secure foundation. Each case must be considered on its

merits. Having determined the horizontal dimensions by reference to the allowable unit pressure on the soil, the depth or thickness of the foundation depends upon its size and that of the bottom of the pier that rests upon it. The thickness will probably be sufficient if a line drawn from the outside edge of the bottom of the pier to the bottom edge of the foundation has a batter of not more than 1 to 2 ; thus, if the foundation is 6 inches larger each way than the bottom of the pier, its thickness should be not less than 1 foot. With good Portland cement concrete this would distribute the pressure over the entire bottom of the foundation. From Diagram No. 1 the quantities may be taken for the pier foundations shown in Fig. 8, which were designed on the foregoing principles to carry the roof and the load that has been described. The estimated pressure on the soil in this case is about 3.8 tons.

FLOOR.

There should be a smooth concrete floor in all covered reservoirs. Its thickness is dependent upon the conditions of the particular reservoir. If the material in which it is built is such that there is little danger of outward leakage, and there is no likelihood of an upward water pressure to lift the floor when the reservoir is emptied, a thickness of 3 or 4 inches is sufficient. The reservoirs at Brookline, Newton, and Wellesley had floors 4 inches thick ; the floor of the Ashland filter was 3 inches. If, on the contrary, the earth is pervious, and the movement of water when the reservoir is full will be away from it, the floor should be at least 6 inches thick. From his experience in the construction of and subsequent observation of a number of open reservoirs, and also from experiments on concrete of different thicknesses, the writer believes that with heads of 20 feet and under, 6 inches of good Portland cement concrete is, or becomes in a short time, very effective in preventing seepage. It should be plastered or finished with rich cement mortar. An excellent method for floors is to finish the concrete as soon as it is rammed, before it begins to set, with mortar mixed for the purpose. If a surplus of water stands on the concrete after ramming, good work can be done by spreading dry cement on and working it to a smooth, close surface with trowels. The liability of separation and peeling off which exists in plastering that has been done after the concrete has set is thus avoided.

If, when the reservoir is emptied, there will be an upward pressure on the floor, it must be designed to resist it. For this purpose inverted arches may be used, designed to carry the estimated pressure to the piers. The roof arches may be reversed, or the feet of the piers given a greater spread and flat circular arches used. In designing to resist the upward pressure care must be taken that the weight of the reservoir and its earth covering is greater than that of the water displaced, to avoid flotation when it is empty.

The Clinton reservoir is designed to resist this tendency to float, as it is anticipated that at certain seasons the outside water may stand above the reservoir and its earth covering. The latter is made 4½ feet thick to provide the necessary weight. The floor is a series of inverted arches. Where there is no sanitary objection, drainage can be arranged in such a way that there will be no upward pressure when the reservoir is drawn down. With a thin layer of clean gravel or broken stone, and underdrains if necessary, the water under the floor can be collected in a well, and through a pipe tightly set in the concrete floor be delivered into the reservoir when the pressure in the latter is less than that outside. An inward opening flap or check valve must be placed upon the pipe to prevent a loss of water from the reservoir. If drains were carried up the back of the wall, the pressure on the latter would also be relieved.

This arrangement would be undesirable in a sewage or other reservoir, the contents of which must be pumped or treated, as the amount would be increased by a flow from the outside.

PLASTERING.

To prevent leakage from the reservoir, and to secure a smooth surface that will be easy to clean, the inner face of the side walls should be plastered. The best results can be had with two coats, the first of mortar, 2 parts sand to 1 of cement, laid on as thick as it will stay, to even up the inequalities of the wall. This coat should not be smoothed. The last coat to be of neat cement ⅛ to ¼ inch thick, thoroughly rubbed on with a trowel and nicely smoothed. If there is an outside pressure from water in the ground, it must be reduced by pumping during the plastering and until it is set. Under such conditions the outside should be plastered, if for any reason it is desirable to permanently exclude the ground water.

Diagram No. 5 gives the number of square yards of the plaster-

ing on the walls of reservoirs of different dimensions. The depths for which the diagram is figured is that from the floor to the high-water line.

MISCELLANEOUS ITEMS.

There are a number of items that will vary in different reservoirs. Among these are the piping, gates, manholes, ventilators, ladders, and, if an automatic recording gage is used, a small building and the apparatus itself. The cost of these items will be from 7 to 12 per cent. of the total. Seeding and sodding the top and slopes are included in the above.

TOTAL COST OF RESERVOIRS.

On the diagrams that accompany this paper are given the quantities of the material in the different parts of the reservoirs of the type described in the paper and shown on the sketches. With some of them there is a multiplying diagram by which the cost of such quantities at various prices per unit may be found. With the diagrams an estimate of the quantity of material and the cost of a reservoir of any dimensions within the limits of the diagrams can be readily made that will be correct for this type. A slight change in design, as, for instance, different spacing of the piers or minor changes in the form of the parts, will not materially affect the estimate.

For making preliminary estimates with even less work than the above entails, and for rapidly determining the economic ratio of depth to area for any desired capacity, Diagram No. 6 has been prepared for round reservoirs and Diagram No. 7 for square ones. These diagrams give the capacities in gallons and the cost in dollars for all of the dimensions within their limits. They were prepared by taking the sum of the cost of all of the items at the unit prices given in Table No. 11, and adding 10 per cent. to this sum for the miscellaneous items. The value of this diagram in finding the economic ratio of depth to horizontal dimensions is not limited to this type, as this ratio will be approximately the same for others. It is believed that it will be found useful in preliminary estimates for other types and at other unit prices by applying such corrections as the engineer believes to be necessary.

Table No. 11.

Unit Prices of Quantities in Covered Reservoirs.

Earth excavation	per cubic yard	$0.50
Rubble or concrete in walls, pier foundations and floors	,, ,, ,,	6.00
Concrete in roof	,, ,, ,,	6.50
Brickwork in piers	,, ,, ,,	13.00
Plastering walls	,, square ,,	.25
Plastering floor	,, ,, ,,	.15
Gravel on roof arches	,, cubic ,,	1.00
Steel ring	per pound in place	.05
Centers, etc.	per square foot for total area of reservoir	.15

Table No. 12 gives the cost of reservoirs of certain capacities when built with economic dimensions. *Caution.* — As prices have risen materially since Diagrams 6 and 7 were prepared, it is probable that a percentage should be added to the results for present use.

It is perhaps needless to caution the reader against using the designs or the quantities given in the paper unless the conditions are substantially similar to those described, or until proper modifications are made.

Table No. 12.

Cost of Covered Reservoirs when Built with Economic Dimensions.

Taken from Diagrams 6 and 7.

Capacity.	Round Reservoirs.			Square Reservoirs.		
Gallons.	Diam.	Depth.	Cost.	Side.	Depth.	Cost.
250,000	60	12	$4,700	54.5	11	$4,800
500,000	75	16	7,800	69.5	14	8,100
750,000	88	17	10,500	79.5	16	11,000
1,000.000	98	18	12.850	88.5	17	13,550
1,250,000	106.5	19	15,200	99.5	17	16,050
1,500,000	115.5	19	17,550	106	18	18,400
1.750.000	120	21	19,950	111.5	19	21,700
2,000.000	125	22	22,000	118.5	19	22,900
2,500,000	134	24	26,200	130	20	27,300
3,000,000	144	25	30,200	142.5	20	31,450
4,000,000	*166	*25	37,900	153.5	23	39,500
5.000,000	*186	*25	45,600	*165	*25	47.400

*These are not the economic dimensions. The diagram does not give greater depths than 25 feet. Moderate departures may be made from the economic dimensions, in either direction, without greatly increasing the cost, as shown by the following table: —

Cost of 1,500,000 Gallons Capacity with Different Dimensions.

Gallons.	Diam.	Depth.	Cost.
1,500,000	112	20.5	$17,600
1,500.000	115.5	19	17,550
1.500,000	118	18.5	17.600
1,500.000	150	11.5	19,900

Reservoir Covering of Concrete and Steel.

The successful use of concrete with steel imbedded within it in floors that are required to sustain heavy loads suggests that this method of construction might be used to advantage in the covering of reservoirs. The writer has made some investigations and inquiries that lead him to believe that, with a simple construction of piers

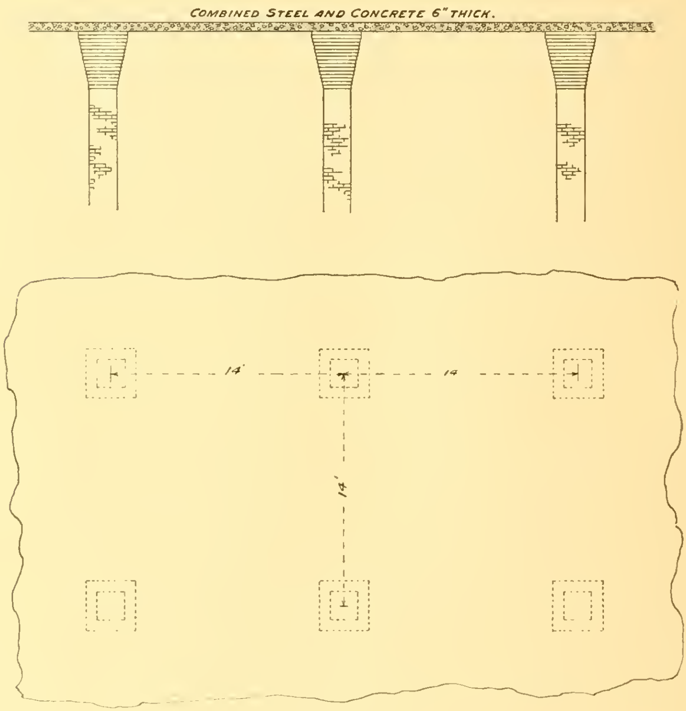
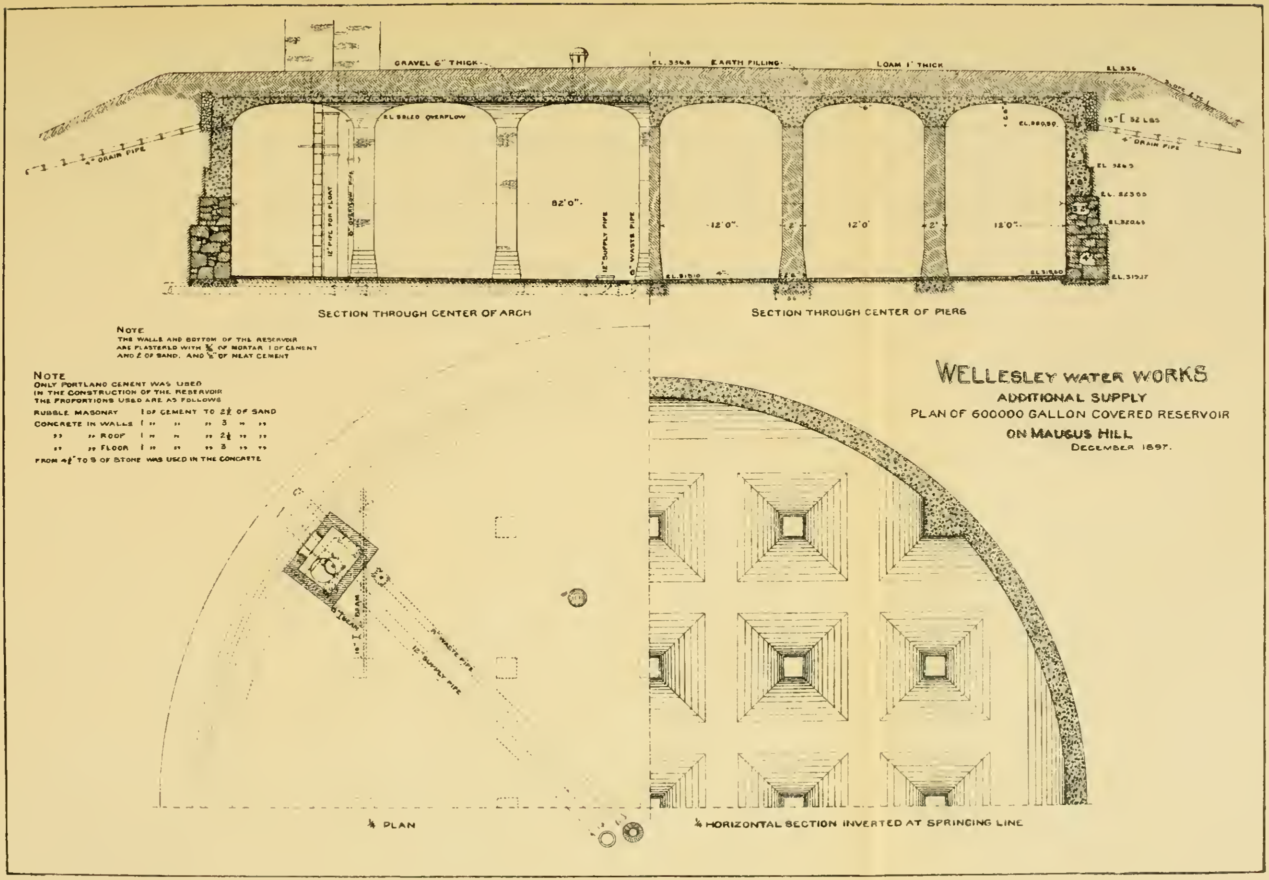


Fig. 9.

and a continuous sheet of concrete with steel imbedded in it, a thickness of 6 inches of first-class Portland cement concrete and a suitable arrangement of "expanded metal" will safely carry the ordinary load on the roof of a covered reservoir or filter, with a clear space of 10 or 12 feet between the piers. Fig. 9 shows a possible arrangement in which the heads of the piers are enlarged, thus reducing the clear span.


GRAVEL 6" THICK
EARTH FILLING
LOAM 1" THICK
4" DRAIN PIPE
EL 328.20 OVERFLOW
12" PIPE FOR FLOAT
8" OVERFLOW PIPE
82'0"
12" SUPPLY PIPE
8" WASTE PIPE
12'0"
15" [32 LBS
4" DRAIN PIPE
SECTION THROUGH CENTER OF ARCH
SECTION THROUGH CENTER OF PIERS
NOTE
THE WALLS AND BOTTOM OF THE RESERVOIR ARE PLASTERED WITH ¾" OF MORTAR 1 OF CEMENT AND 2 OF SAND, AND ⅛" OF NEAT CEMENT
NOTE
ONLY PORTLAND CEMENT WAS USED IN THE CONSTRUCTION OF THE RESERVOIR
THE PROPORTIONS USED ARE AS FOLLOWS
RUBBLE MASONRY 1 OF CEMENT TO 2½ OF SAND
CONCRETE IN WALLS 1 " " " 3 " "
" " ROOF 1 " " " 2½ " "
" " FLOOR 1 " " " 3 " "
FROM 4½" TO 5 OF STONE WAS USED IN THE CONCRETE
WELLESLEY WATER WORKS
ADDITIONAL SUPPLY
PLAN OF 600000 GALLON COVERED RESERVOIR
ON MAUGUS HILL
DECEMBER 1897.
12" SUPPLY PIPE
8" WASTE PIPE
¼ PLAN
¼ HORIZONTAL SECTION INVERTED AT SPRINGING LINE

One advantage of this form of construction lies in the simplicity and economy of the centering required.

It is estimated that, at the present prices, the cost of the expanded metal is about 7½ cents per square foot for the area covered. The concrete, the cost of which would probably not exceed $7 per cubic yard in place, including the centering or forms, would cost about 13 cents per square foot, making a total of 20 or 21 cents, while the arched vaulting costs from 30 to 35 cents per square foot.

PROCEEDINGS.

Quarterly Meeting.

Young's Hotel, Boston, December 13, 1899.

President Cook in the chair.

The following members and guests were present: —

Members.

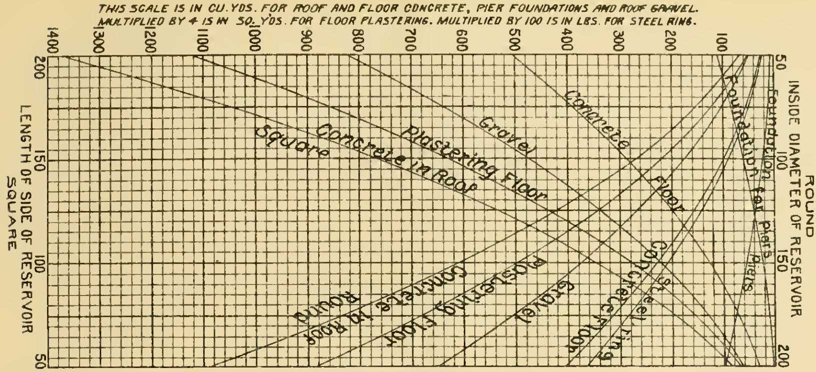
Charles H. Baldwin, Lewis M. Bancroft, Roland D. Barnes, R. S. Bartlett. James W. Blackmer, E. C. Brooks, Fred Brooks, George A. P. Buckman. George Cassell, John T. Cavanagh, George F. Chace, Charles E. Chandler, G. L. Chapin, John C. Chase, William F. Codd, Freeman C. Coffin, R. C. P. Coggeshall, Byron I. Cook, Henry A. Cook, J. W. Crawford, Arthur W. Dean, Charles H. Eglee, Loring N. Farnham, Richard J. Flinn, F. F. Forbes, Frank L. Fuller. Harry F. Gibbs, Julius C. Gilbert, T. C. Gleason, Albert S. Glover, J. A. Gould, Frederick W. Gow, E. H. Gowing, J. C. Hammond, Jr., John C. Haskell, L. M. Hastings, T. G. Hazard, Jr., William R. Hill, Horace G. Holden, H. R. Johnson, Horace Kingman. Wilbur F. Learned, James W. Locke, Frank E. Merrill, Thomas Naylor, Frank L. Northrop, W. J. Sando, Charles W. Sherman, Walter H. Sears, George A. Stacy, Edwin A. Taylor, Robert J. Thomas, Harry L. Thomas, William H. Thomas, D. N. Tower, W. H. Vaughn, John Venner, William W. Wade, Charles K. Walker.

Associate Members.

Ashton Valve Co.; Coffin Valve Co.; Hersey Mfg. Co., by J. A. Tilden, Fred A. Smith, A. A. Blossom; Kennedy Valve Co., by M. J. Brosnan; Lead Lined Iron Pipe Co., by T. C. Dwyer; Ludlow Valve Mfg. Co., by H. F. Gould; Neptune Meter Co., by H. H. Kinsey; Rensselaer Mfg. Co., by Fred S. Bates; A. P. Smith Mfg. Co., by W. H. Van Winkle; U. S. Cast Iron Pipe & Foundry Co.; Sumner & Goodwin Co., by F. B. Sumner; Thomson Meter Co., by S. B. Higley; Union Water Meter Co.; The George Woodman Co.

Guests.

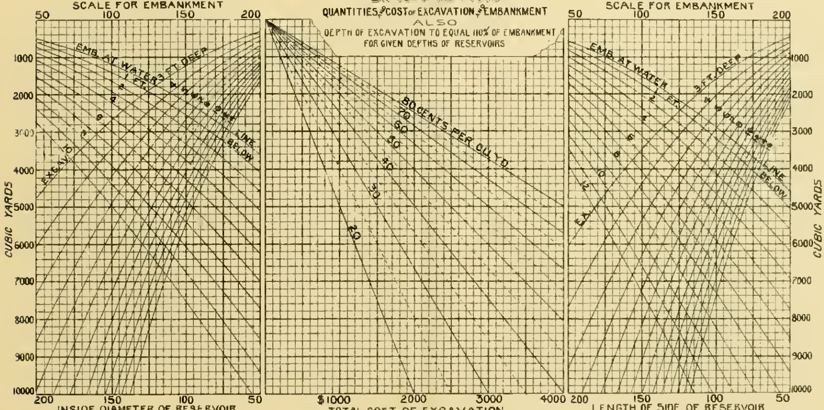
L. C. Dean, Attleboro, Mass.; James M. Buntin, John H. Lewis, E. P. Allister. George W. Travis, Natick, Mass.; George Goodhue, Frederick A. Aucher, Water Commissioner, Syracuse, N. Y.; Joshua Morse, Hingham, Mass.; Mr. Robinson, Plymouth, Mass.; W. E. Mayberry, Braintree, Mass.; M. E. Kennedy, L. Z. Carpenter, Attleboro, Mass.



NOTE:
SEE SCALE AT TOP FOR ROUND RESERVOIRS
" " "BOTTOM" SQUARE "

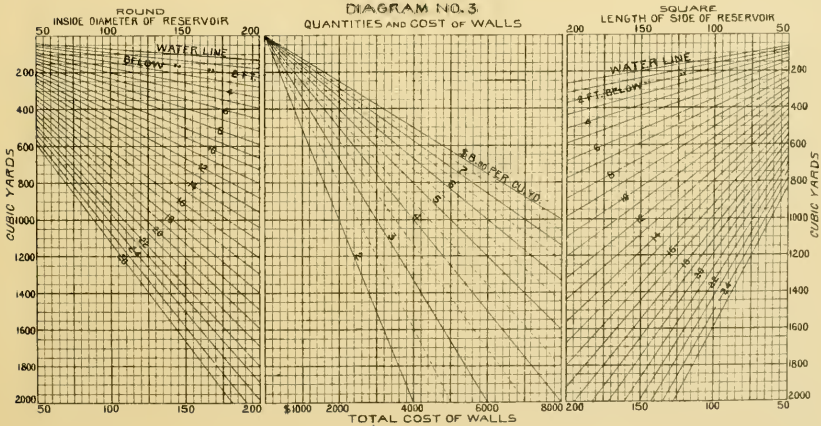
COVERED RESERVOIRS
DIAGRAM NO. 1

COVERED RESERVOIRS
DIAGRAM NO. 2
QUANTITIES & COST OF EXCAVATION & EMBANKMENT
ALSO
DEPTH OF EXCAVATION TO EQUAL 110% OF EMBANKMENT FOR GIVEN DEPTHS OF RESERVOIRS



NOTE: Quantities of Embankment contain 10% added for Shrinkage

COVERED RESERVOIRS
DIAGRAM NO. 3
QUANTITIES AND COST OF WALLS



The following gentlemen were elected to membership in the Association: —

Resident Active. — Stephen DeM. Gage, Biologist Massachusetts State Board of Health, Lawrence Experiment Station; L. Z. Carpenter, Superintendent Attleboro Water Works; William A. Kilburn, Secretary Water Commissioners, Lancaster; William L. Kimball, Inspector Metropolitan Water Board; John L. Howard, Assistant Engineer Metropolitan Water Board; Leonard Lee Street, Engineering Department, Metropolitan Water Works; James W. Killam, Metropolitan Water Works, Reading; Charles E. Haberstroh, Assistant Superintendent Metropolitan Water Works, South Framingham; Carl J. Youngren, Clerk Metropolitan Water Works, Boston; Sidney K. Clapp, Metropolitan Water Works, Boston; George W. Travis, Superintendent Natick Water Works; Andrew D. Fuller, Assistant Engineer Sewerage and Surface Drainage Systems, Boston.

Non-Resident Active. — William B. Ewing, C.E., La Grange, Ill.

Associate. — Edward Robinson, Wells Light Mfg. Co., New York City.

George F. Chace, Superintendent, Taunton, Mass., read a paper entitled "A Rumpus in Collecting Meter Rates: Causes and Consequences." Mr. J. C. Gilbert followed with a statement concerning recent trouble he had had of the same character.

Dr. Frederick S. Hollis, Biologist of the Metropolitan Water Works, then read a paper on "Removing Organisms from Water." Mr. Hill read a statement in reply, and the subject was further discussed by Messrs. R. S. Weston, Horatio N. Parker, J. C. Haskell, W. R. Hill, and F. S. Hollis.

A paper descriptive of the Glasgow Water Works, contributed by James M. Gale, C.E., Engineer-in-Chief Loch Katrine Water Works, Glasgow, Scotland, was read by Mr. Charles W. Sherman.

A paper by Freeman C. Coffin, C.E., entitled "Covered Reservoirs and their Design," was presented by title.

Adjourned to January 10, 1900.

Adjourned Meeting.

Young's Hotel, Boston, January 10, 1900.

President Cook in the chair.

The following members and guests were present: —

Members.

Francis E. Appleton, Wm. E. Badger, Charles H. Baldwin, Lewis M. Bancroft, Roland D. Barnes, George W. Batchelder, Joseph E. Beals, James W. Blackmer, 2d, George Bowers, Dexter Brackett, E. C. Brooks,

Fred Brooks, James Burnie, George F. Chace, G. L. Chapin, John C. Chase, R. C. P. Coggeshall, Wm. Downey, Eben R. Dyer, John W. Ellis, George E. Evans, John N. Ferguson, F. F. Forbes, William E. Foss, Frank B. French, Frank L. Fuller, George W. Fuller, Harry F. Gibbs, Albert S. Glover, J. A. Gould, Frederick W. Gow, E. H. Gowing, John C. Haskell, V. C. Hastings, Louis E. Hawes, William E. Hawks, T. G. Hazard, Jr., Horace G. Holden, E. W. Kent, Willard Kent, Patrick Kieran, Morris Knowles, James W. Locke, A. E. Martin, Frank E. Merrill, Charles E. Peirce, John H. Perkins, J. B. Putnam, Walter H. Richards, W. W. Robertson, Harley E. Royce, George O. Sanders, Charles W. Sherman, W. H. Sears, M. A. Sinclair, J. Waldo Smith, Robert W. Taber, Lucian A. Taylor, Robert J. Thomas, Harry L. Thomas, William H. Thomas, W. H. Vaughn, William W. Wade, Charles K. Walker, George E. Wilde, William F. Williams, and George E. Winslow.

Associate Members.

Ashton Valve Co., by C. W. Houghton; Chadwick Lead Works, by A. H. Brodrick; Chapman Valve Mfg. Co., by E. F. Hughes; Coffin Valve Co., by H. L. Weston; Hersey Mfg. Co., by J. A. Tilden and Albert A. Blossom; Ludlow Mfg. Co., by S. F. Ferguson; National Meter Co., by John C. Kelley and J. G. Lufkin; Neptune Meter Co., by H. H. Kinsey; A. P. Smith Mfg. Co., by W. H. Van Winkle; B. F. Smith & Bro., by B. F. Smith; Sumner & Goodwin Co., by F. D. Sumner; Union Water Meter Co., by Frank L. Northrop; U. S. Cast Iron Pipe & Foundry Co., by John M. Holmes and E. T. Stewart; R. D. Wood & Co., by W. E. Newhall and E. T. Krewson; The George Woodman Co., by H. A. Gorham.

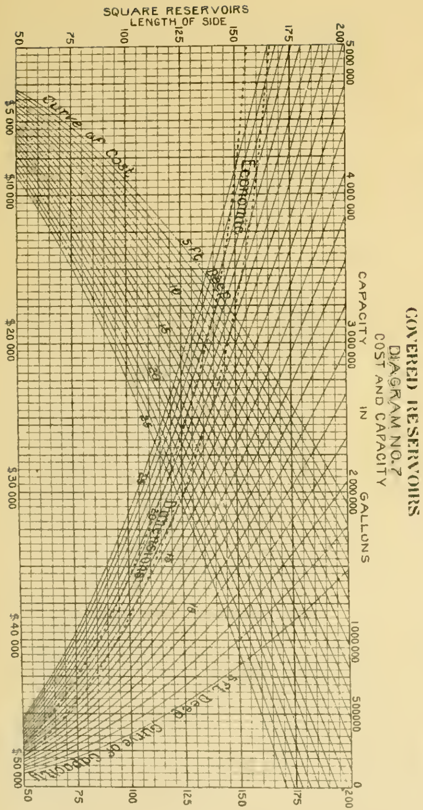
Guests.

J. M. Anderson, Worcester, Mass.; Charles F. Bancroft, Winchester. Mass.; E. E. Brownell, Dayton, Ohio; Edward Backus, Somerville, Mass.; M. J. Dowd, Frank L. Weaver, H. C. Taft, Members Lowell Water Board, Lowell, Mass.; George M. Hawks, Secretary, Bennington, Vt.; S. C. Hunt, John L. G. Mason, Members Water Board, New Bedford, Mass.; A. T. Safford, Assistant Engineer Locks & Canals Co., Lowell, Mass.; Charles E. Smith, Lincoln, Mass.; Edmund B. Weston, Consulting Engineer, Providence, R. I.; C. M. Woodward, Water Commissioner, West Springfield, Mass.; Gardner T. Swarts, Secretary Rhode Island State Board of Health, Providence, R. I.; F. V. Fuller, J. F. Monahan, Boston, Mass.

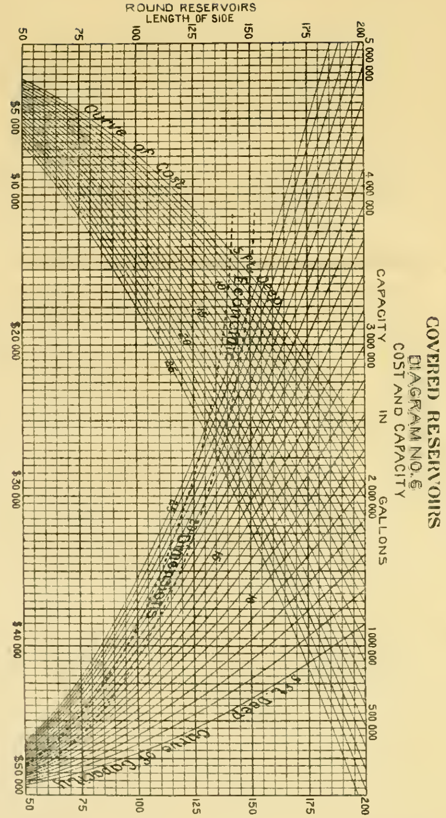
The following were elected members: —

Resident Active. — Edward S. Larned, Metropolitan Water Supply, South Framingham.

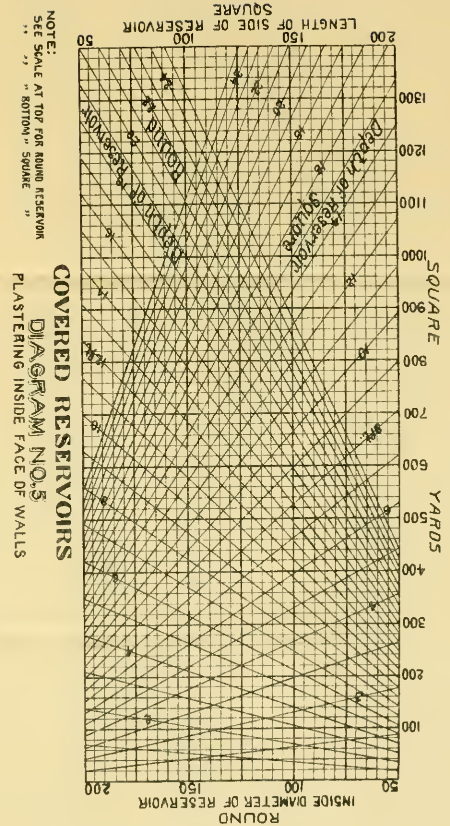
Non-Resident Active. — T. Schuyler Miller, First Assistant Chemist to the Department of Water Supply, Brooklyn, N. Y.; Allan W. Cuddeback, Assistant Engineer Passaic Water Co., Paterson, N. J.; William Murdock, Chief Engineer and Superintendent St. John Sewerage and Water Works, St. John, N. B.



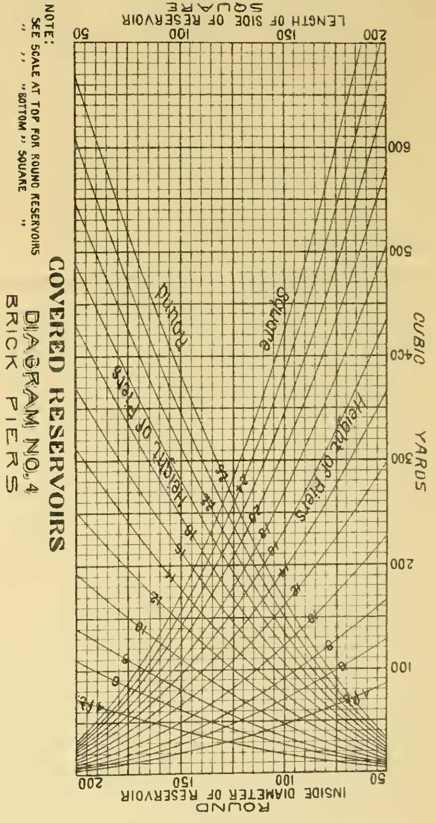
COVERED RESERVOIRS
DIAGRAM NO.7
COST AND CAPACITY



COVERED RESERVOIRS
DIAGRAM NO.6
COST AND CAPACITY



COVERED RESERVOIRS
DIAGRAM NO.5
PLASTERING INSIDE FACE OF WALLS



COVERED RESERVOIRS
DIAGRAM NO.4
BRICK PIERS

Edmund B. Weston, Consulting Engineer, Providence, R. I., read a paper entitled "The Subsidence Gravity System of Mechanical Filtration." The paper was discussed by Dr. Gardner T. Swarts, Secretary of the State Board of Health of Rhode Island, George W. Fuller, and R. S. Weston.

E. E. Brownell, Electrical Engineer, Dayton, Ohio, read a paper on "Electrolysis from Facts and Figures."

Adjourned to February 14, 1900.

Adjourned Meeting.

Young's Hotel, Boston, February 14, 1900.

President Cook in the chair.

The following members and guests were present: —

Members.

Lewis M. Bancroft, Joseph E. Beals, George Bowers, E. C. Brooks, Fred. Brooks, George F. Chace, G. L. Chapin, H. W. Clark, A. W. Cuddeback, John C. Chase, R. C. P. Coggeshall, Byron I. Cook, J. W. Crawford, Arthur W. Dean, Charles H. Eglee, John N. Ferguson, F. F. Forbes, Frank L. Fuller, E. H. Gowing, Frank E. Hall, E. A. W. Hammatt, George W. Harrington, J. C. Haskell, Horace G. Holden, F. S. Hollis, John L. Howard, Willard Kent, Patrick Kieran, Leonard P. Kinnicutt, E. S. Larned, A. E. Martin, Theodore H. McKenzie, F. E. Merrill, Thomas Naylor, W. W. Patch, Horatio N. Parker, J. B. Putnam, W. W. Robertson, W. J. Sando, Charles W. Sherman, Walter H. Sears, George A. Soper, George A. Stacy, Robert J. Thomas, Harry L. Thomas, William H. Thomas, D. N. Tower, W. H. Vaughn, William W. Wade, George W. Travis, George E. Winslow.

Associate Members.

Ashton Valve Co., by C. W. Houghton; Chapman Valve Mfg. Co., by Edward F. Hughes; Coffin Valve Co., by H. L. Weston; M. J. Drummond & Co., by Lester E. Wood; Hersey Mfg. Co., by Albert S. Glover; Kennedy Valve Co., by M. J. Brossian; Lead Lined Iron Pipe Co., by Thomas E. Dwyer; Ludlow Valve Mfg. Co., by H. E. Gould: Henry F. Jenks, Pawtucket, R. I.; National Meter Co., by J. G. Lufkin; Neptune Meter Co., by H. H. Kinsey; Perrin, Seamans & Co., by Harold N. Bond; Rensselaer Mfg. Co., by Fred S. Bates; Builders' Iron Foundry, by F. N. Comet; A. P. Smith Mfg. Co., by W. H. Van Winkle; Thomson Meter Co., by Henry C. Folger and S. D. Higley; Union Water Meter Co., by A. S. Otis and F. L. Northrop; U. S. Cast Iron Pipe & Foundry Co., by E. T. Stuart; R. D. Wood & Co., by E. F. Krewson.

GUESTS.

E. D. Eldredge. Treasurer Onset Water Co., Brookline, Mass.; F. B. French, Superintendent Public Works, Woburn, Mass.; Charles F. Knowlton, Commissioner Public Works, Quincy, Mass.; H. S. Macksey, Assistant Superintendent, Boston, Mass.; S. C. Prescott, Boston, Mass.; Wm. T. Sullivan, Engineer, Lowell, Mass.: F. L. Weaver, President Water Board, Lowell, Mass.; J. P. Wood, Marlboro, Mass.; J. N. Gilligar, Natick, Mass.

The following gentlemen were elected to membership: —

Resident Active. — Bennett F. Davenport, Chairman Water Commissioners, Watertown, Mass.; Edward D. Eldredge, Superintendent Wareham Water Works, Brookline, Mass.; Wm. F. Sullivan, Lowell Water Works, Lowell, Mass.; Frank B. Wilkins, Superintendent Water Works, Milford, N. H.

Non-Resident Active. — J. L. Ludlow, Winston, N. C.; N. B. Livermore, Superintendent Water Works. San Diego, Cal.; E. C. Amos, Civil Engineer Montreal, Can.

A paper entitled "The Ozonization of Water," by Dr. George A. Soper, Engineer and Chemist, New York City, was read by the author and discussed by Prof. L. P. Kinnicutt, Dr. F. S. Hollis, and Messrs. H. W. Clark, Horatio N. Parker, J. C. Haskell, and George F. Chace.

Mr. John L. Howard, Assistant Engineer Metropolitan Water Works, then read a paper entitled "The Construction of the Fells Reservoir for the Metropolitan Water Works," illustrated by lantern slides. It was discussed by Dr. F. S. Hollis.

A third paper on "Cement Lined Service Pipe, with a brief discussion of lead poisoning resulting from use of lead for service pipe," by Fayette F. Forbes, C.E., Superintendent Brookline Water Works, was then read by Mr. Forbes, and was discussed by Messrs. Frank L. Fuller, Charles W. Sherman, T. H. McKenzie, George F. Chace, George A. Stacy, F. E. Merrill, George E. Winslow, E. A. W. Hammatt, Byron I. Cook, Harry W. Clark, and Walter W. Patch.

On motion, the meeting adjourned.

NEW ENGLAND WATER WORKS ASSOCIATION.

ORGANIZED 1882.

Vol. XIV. June, 1900. No. 4.

THE ALBANY WATER FILTRATION PLANT.

BY ALLEN HAZEN, CIVIL ENGINEER, NEW YORK CITY.

[*Presented September 13, 1899*]*

HISTORICAL.

Albany, N. Y., was originally supplied with water by gravity from reservoirs on small streams west and north of the city. In time, with increasing consumption, the supply obtained from these sources became inadequate, and an additional supply from the Hudson River was introduced. The water was obtained from the river through a tunnel under the Erie Basin, and a pumping station was erected in Quackenbush Street to pump it to reservoirs, one of which served also as the distributing point for one of the gravity supplies. The intake, which was used first in 1873, drew water from the river opposite the heart of the city. In recent years, the amount of water drawn from this source has greatly exceeded that obtained from the gravity sources.

Some of the city sewers enter the river above this intake, but most of them are below it. In times of flood, the water thus obtained was polluted by the sewage of only a few of the city sewers; at low-water stages, however, owing to the tidal currents, the water contained much sewage, which was carried upstream to the intake, and the sewage of the city was thus present, in very considerable amount, in its own water supply.

In addition to the pollution from local sources, the river receives

*Presented as an informal talk at the Syracuse convention. In its present form the paper is abstracted by the editor from one read by Mr. Hazen before the American Society of Civil Engineers on January 3, 1900. The cuts have been electrotyped, by permission of the American Society of Civil Engineers, from the paper just referred to, except those on Plate IV, which are from Mr. Hazen's book on Filtration, by permission of John Wiley & Sons.

the sewage of Troy and the surrounding cities, seven or eight miles above, and that of Schenectady, Utica, Rome, and many other places farther away.

Under these conditions the typhoid fever death rate in Albany was excessive. Prof. W. P. Mason, of Troy, made a report in 1885 upon the quality of the water, in which he stated that the water as then used was a source of disease, and should be abandoned at the earliest practicable date. Following this, an attempt was made to secure a ground-water supply, but without results. Studies were then made for gravity sources of supply, mentioned in the reports of the Board of Water Commissioners for the years 1891 to 1893; but the necessary legislation was not obtained.

In 1896 the Board investigated methods of purifying the present supply. The matter was studied by the Board and by its Superintendent, Mr. George I. Bailey, and in January, 1897, the author was engaged to examine the studies which had been made, and to report upon the projects presented. His report recommended the general scheme previously outlined by the Superintendent, namely, to abandon the present intake, and to establish a new one about two miles farther up the river, at a point above all the local sources of pollution, and to pump the water by low-lift pumps to a settling basin, from which it would flow to sand filters, and thence through a pure-water conduit to the present pumping station in Quackenbush Street.

The report was accepted, the recommendations adopted, and the necessary funds were provided; and, in July, 1897, the preparation of plans was begun.

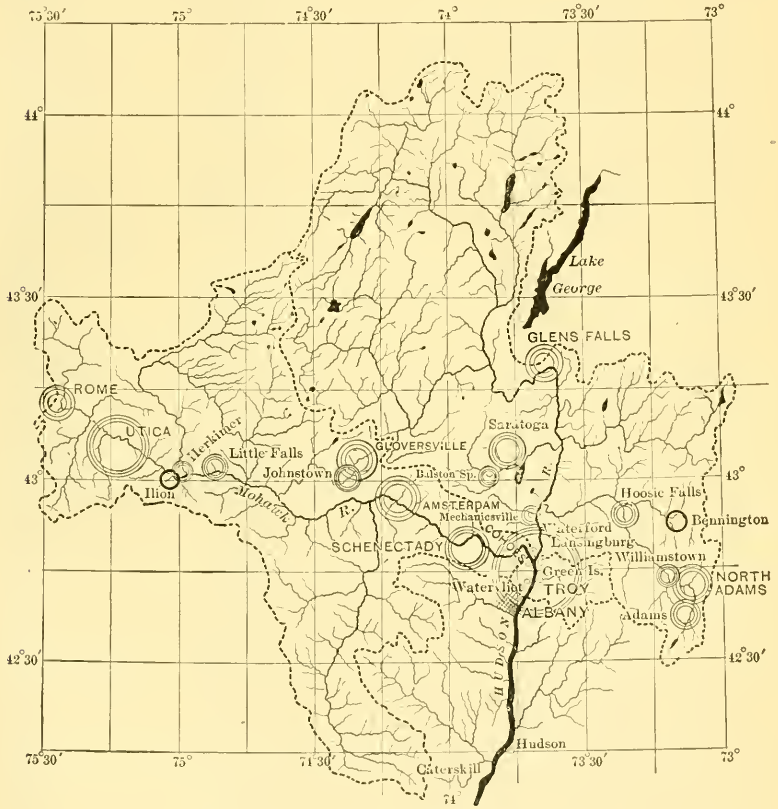
As the pure-water conduit was to be placed in the Erie Canal, and as the work of constructing it necessarily had to be done during the season of closed navigation, plans for this part of the work were prepared first. The contract was let in November, 1897, and that part of the work under the canal was completed before navigation opened, May 1, 1898.

The contract for the filters and sedimentation basin was awarded in February, 1898, and work was commenced in April; but, owing to various reasons connected with the installation of a very elaborate contractors' plant, work was not pushed actively until August, 1898. Contracts for the pumping machinery, and for the pumping station and intake, were let in June and August, 1898, and the work was carried out during the fall and winter. Construction was sufficiently

advanced so that a part of the plant was put in operation on July 27, 1899. The old intake was closed on September 6, 1899, since which time no unfiltered river water has been pumped to the city.

SOURCE OF SUPPLY.

The source of supply is the Hudson River, which, at the point of intake, has a drainage area of 8 240 square miles. Of this, 4 570



WATERSHED OF HUDSON RIVER ABOVE INTAKE

Note:- Circles show population in 1880, 1890, and estimated population for 1900. A single circle indicates no growth or very slow growth.

SCALE

0 10 20 30 40 50 MILES

0 10 20 30 40 50 60 70 80 90 100 KILOMETERS

FIG. 1.

square miles are tributary to the Hudson above Troy, 3 502 are tributary to the Mohawk, and 168 are tributary to the Hudson below the Mohawk.

No gagings of the river at this point are available. The average annual flow of the stream probably amounts to at least 1 000 000 gallons per square mile per day, or over 8 000 000 000 gallons per day. The minimum flow is only a small fraction of this amount. Mr. George W. Rafter, who has made a study of the flow of the Upper Hudson,* estimates the minimum flow at Mechanicsville at 0.24 cubic foot per second per square mile of tributary drainage area. Assuming that this figure applies to the whole of the Hudson above Troy, and taking a somewhat lower figure, namely, 0.15 cubic foot per second per square mile, for the discharge of the Mohawk and of the Hudson below Troy, we arrive at a minimum flow of the Hudson at Albany of 1 657 cubic feet per second, or 1 060 000 000 gallons per 24 hours, being, in round numbers, 100 times the average amount of water now taken from the river for water works purposes, and at least fifty times the maximum.

Pollution of the Raw Water. — Table No. 1 gives the names of the cities and larger towns upon the river above the intake, with estimated populations and distances. The largest of these places are also shown upon the map of the watershed, Fig. 1.

Without entering into a detailed discussion, it may be said that the amount of sewage, with reference to the size of the river and the volume of flow, is a fraction less than that at Lawrence, Mass., but the pollution is much greater than that of most American rivers from which municipal water supplies are taken.

Position of Intake. — The general form of the river channels near the new plant is shown in Figs. 2 and 3. Opposite the plant is a long, narrow island. The land upon which the filter plant is built fronts the back channel of the river. This back channel carried formerly a considerable proportion of the river's flow, but, to improve navigation, the United States Government has constructed a dike, the top of which is about 5 feet above low water, and this dike cuts off most of the flow through this channel at ordinary river stages. At flood stages the dike is overtopped, and the channel takes a large amount of water.

The question arose, whether to build an intake across the back

* Report of the State Engineer and Surveyor for 1895, p. 119.

TABLE No. 1. — CITIES, TOWNS, AND VILLAGES ON THE WATERSHED OF THE HUDSON RIVER ABOVE ALBANY, WITH POPULATIONS OF 1 000 AND OVER.

Place.	County.	Approximate distance above intake. Miles.	Population in 1880.	Population in 1890.	Population in 1900. (Estimated.)
Troy	Rensselaer	4	56 747	60 956	65 470
Watervliet	Albany	4	8 820	12 967	19 040
Green Island	Rensselaer	5	4 160	4 463	4 788
Waterford	Saratoga	9	1 822	1 822	1 822
Cohoes	Albany	8	19 416	22 509	26 450
Lansingburg	Rensselaer	8	7 432	*10 550	14 980
Mechanicsville	Saratoga	19	1 265	2 679	5 358
Schaghticoke	Rensselaer	27	1 258	1 258	1 258
Schenectady	Schenectady	28	13 655	19 002	26 450
Schuylerville	Saratoga	32	1 617	1 387	1 190
Greenwich	Washington	39	1 231	1 663	2 247
Fort Edward	Washington	43	4 680	4 424	4 182
Hoosic Falls	Rensselaer	44	4 530	7 014	10 860
Amsterdam	Montgomery	44	9 466	17 336	31 730
Cambridge	Washington	45	1 482	1 598	1 723
Sandy Hill	Washington	46	2 487	2 895	3 371
Glens Falls	Warren	49	4 900	9 509	18 450
South Glens Falls	Saratoga	49	1 083	1 606	2 387
Saratoga Springs	Saratoga	51	8 421	11 975	17 010
Ballston Springs	Saratoga	51	3 011	3 527	4 131
Fultonville	Montgomery	54	881	1 122	1 429
Fonda	Montgomery	54	944	1 190	1 500
Johnstown	Fulton	56	5 013	7 768	12 040
Bennington, Vt.	Bennington	56	3 971	3 971	3 971
Gloversville	Fulton	58	7 133	13 864	26 930
Canajoharie	Montgomery	63	2 013	2 089	2 168
Williamstown, Mass.	Berkshire	63	3 394	4 221	5 250
Corinth	Saratoga	64	510	1 222	2 444
North Adams, Mass.	Berkshire	68	10 191	16 074	25 340
Luzerne	Warren	68	468	868	1 610
Schoharie	Schoharie	68	1 188	1 028	889
Fort Plain	Montgomery	69	2 443	2 864	3 358
Middleburg	Schoharie	73	1 123	1 139	1 155
St. Johnsville	Montgomery	74	1 072	1 263	1 488
Cobleskill	Schoharie	74	1 222	1 822	2 717
Adams, Mass.	Berkshire	75	5 591	9 213	15 181
Warrensburg	Warren	82	748	893	1 073
Little Falls	Herkimer	82	6 910	8 783	11 160
Herkimer	Herkimer	90	1 353	1 353	1 353
Mohawk	Herkimer	91	1 441	1 806	2 264
Ilion	Herkimer	93	3 711	4 057	4 436
Frankfort	Herkimer	95	1 085	2 291	4 582
Utica	Oneida	101	33 914	44 007	57 090
Whitesboro	Oneida	107	1 370	1 663	2 018
New York Mills	Oneida	108	1 195	1 195	1 195
New Hartford Mills	Oneida	......	710	912	1 171
Oriskany	Oneida	111	597	860	1 239
Clinton	Oneida	121	1 236	1 269	1 303
Rome	Oneida	121	12 194	14 991	18 430
Waterville	Oneida	127	1 734	1 734	1 734
Total, not including rural population			272 838	354 672	479 415
Per square mile			33	43	59

channel and the island to the main channel of the river, or to take water from the more convenient back channel. Each point had its advantages. To determine the relative character of the water,

TABLE No. 2.—Bacterial Examinations of Water from Main Channel and from Back Channel at Proposed Points of Intake.

Date.	Hour.	Approximate state of tide.	Back Channel.		Main Channel.	
			Turbidity.	Bacteria.	Turbidity.	Bacteria.
1898. March 24 . .	3.00 P.M.	Low tide	. . . . . .	2 250	. . . . . .	. . . . . .
April 13 . .	11.00 A.M.	Rising	. . . . . .	1 927	. . . . . .	2 889
20 . .	7.15 A.M.	High	. . . . . .	1 970	. . . . . .	. . . . . .
	8.00 ,,	High	. . . . . .	. . . . . .	. . . . . .	2 165
June 8 . .	12.00 M.*	High	0.04	400	. . . . . .	2 200
20 . .	1.30 P.M.	Falling	0.09	350	. . . . . .	825
24 . .	7.00 A.M.	Low	0.03	1 000	0.04	1 040
	9.20 ,,	Rising	0.03	760	0.04	1 120
	11.40 ,,	Nearly high . .	0.03	600	0.04	1 040
	2.00 P.M.	After high . . .	0.03	300	0.04	4 000
	4.20 ,,	Falling	0.03	1 400	0.04	5 200
	6.40 ,,	Low	0.03	640	0.04	3 600
29 . .	2.00 P.M.	Nearly high . .	. . . . . .	. . . . . .	0.03	2 040
	2.30 ,,	High	0.04	860	. . . . . .	. . . . . .
July 7 . .	9.00 A.M.	High	. . . . . .	. . . . . .	0.03	4 360
	10.00 ,,	After high . . .	0.04	560	. . . . . .	. . . . . .

examinations were made by Dr. George Blumer, of the Bender Hygienic Laboratory, of Albany. The most important results of these examinations are shown in Table No. 2. The results are normal, and represent the condition of the water as it would be ordinarily. They show, in a general way, that the water in the back channel was considerably better than that in the main channel. Occasionally, there was but little difference, and this would always be the case when the river was in flood. At no time was the water in the back channel materially worse than in the main channel.

One of the city sewers enters the river at a point a short distance from the outlet of the back channel, and there was a possibility that sewage therefrom would be carried up this channel by flood tides. On the other hand, the water in the main channel had come directly from the Troy sewers, while that in the back channel was more or less completely cut off from the main current, and was moved back and forth by the tides, and opportunities for natural purification were present in greater degree than in the main channel. These conditions, apparently, more than offset the possible admixture of fresh sewage.

DESCRIPTION OF PLANT.

The filter plant, and all structures connected therewith, are shown

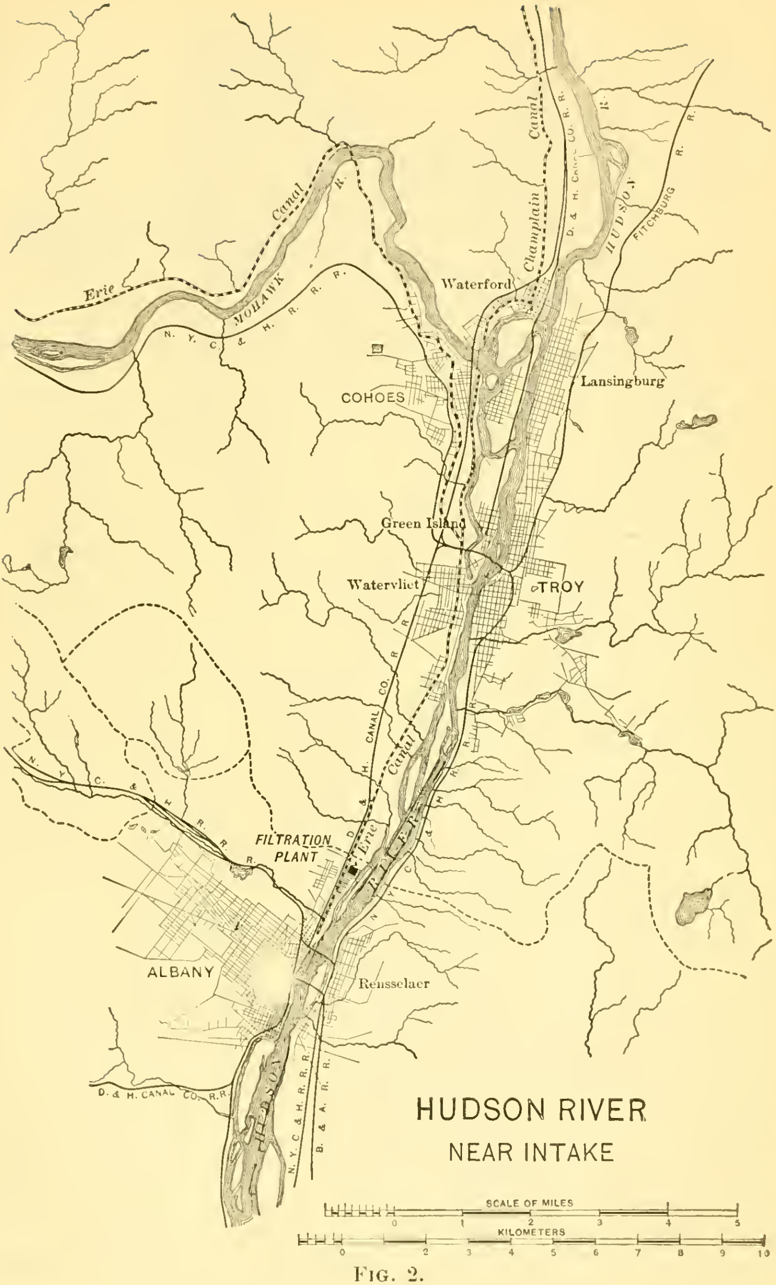
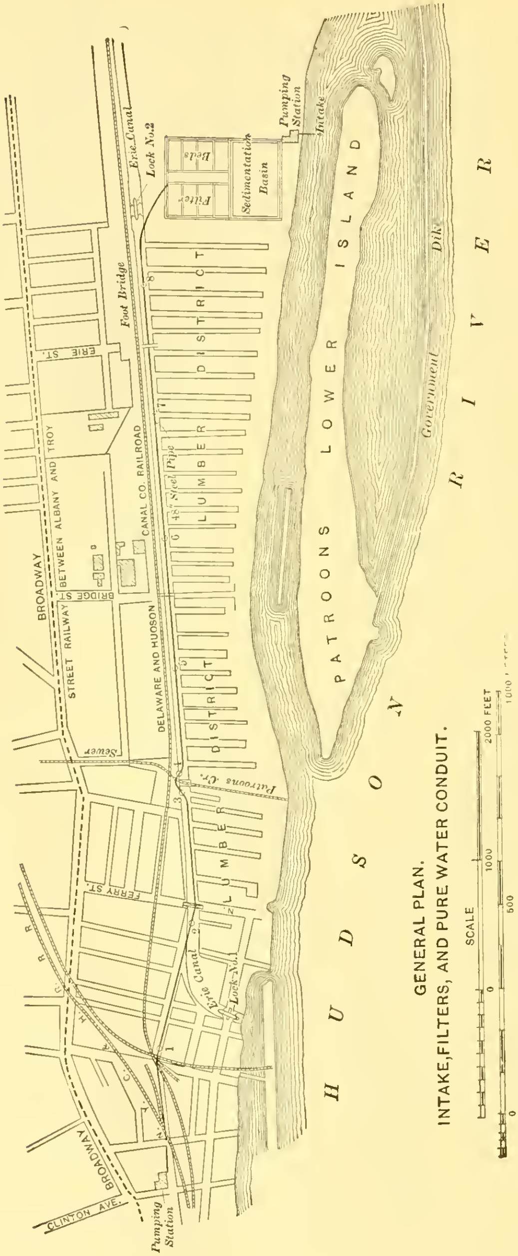

HUDSON RIVER
NEAR INTAKE
Erie Canal
MOHAWK R.
N. Y. C. & H. R. R. R.
Waterford
Champlain Canal
D. & H. CANAL CO. R. R.
HUDSON R.
FITCHBURG R. R.
COHOES
Lansingburg
Green Island
Watervliet
TROY
D. & H. CANAL CO. R. R.
Erie Canal
RIVER
FILTRATION PLANT
ALBANY
Rensselaer
D. & H. CANAL CO. R.R.
HUDSON
N. Y. C. & H. R. R. R.
B. & A. R. R.
SCALE OF MILES
KILOMETERS

FIG. 2.



GENERAL PLAN.
INTAKE, FILTERS, AND PURE WATER CONDUIT.

FIG. 3.

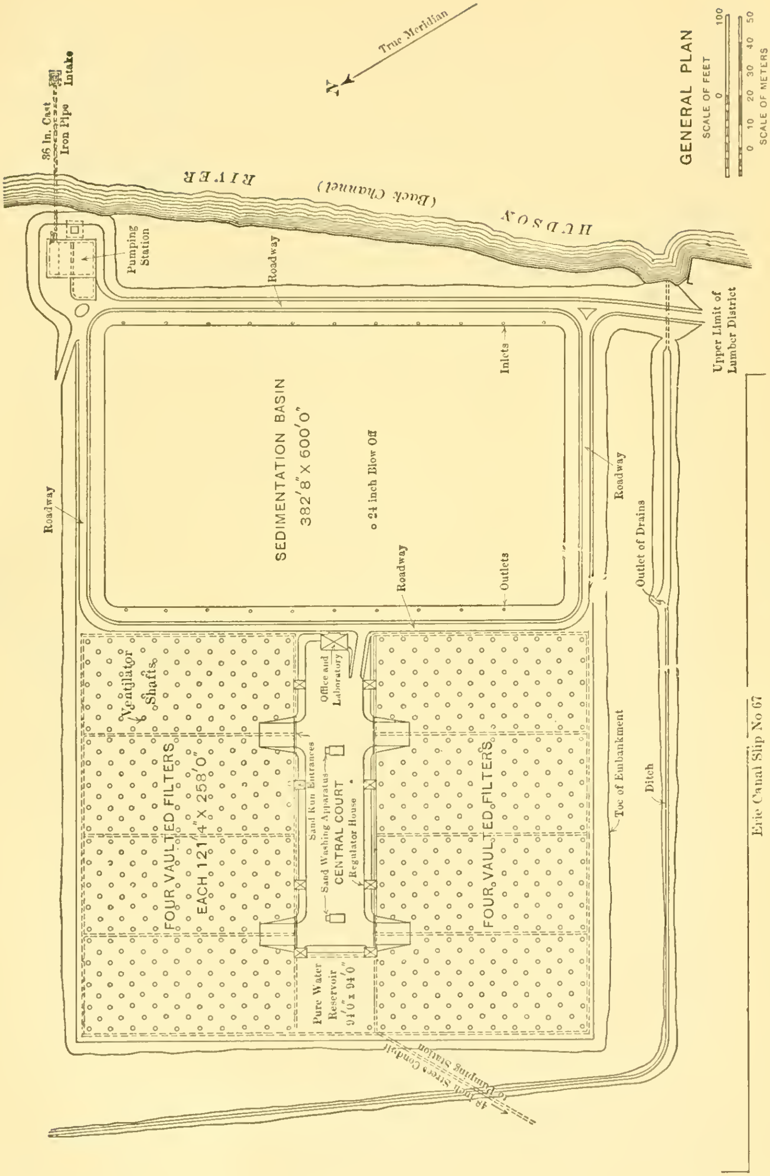
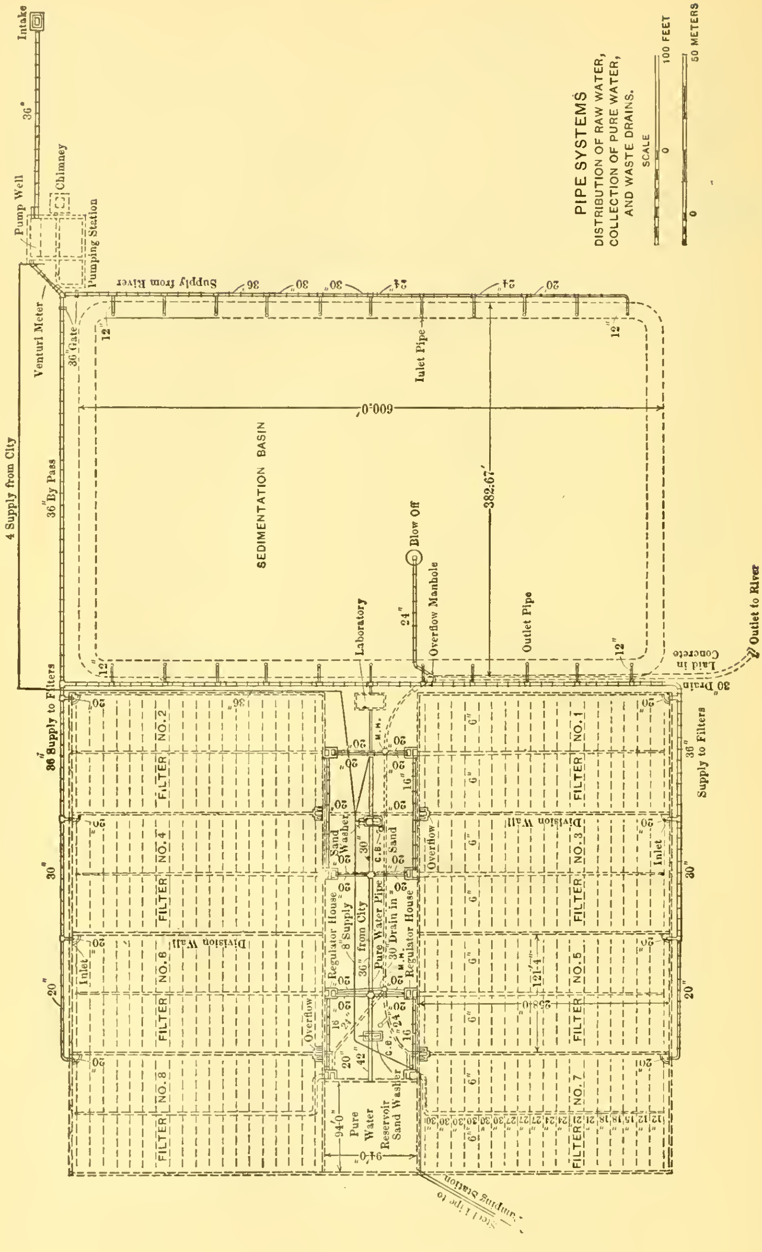

GENERAL PLAN
SCALE OF FEET
0
100
0 10 20 30 40 50
SCALE OF METERS
True Meridian
N
36 In. Cast Iron Pipe
Intake
HUDSON RIVER
(Back Channel)
Pumping Station
Roadway
Upper Limit of Lumber District
Inlets
SEDIMENTATION BASIN
382'8" X 600'0"
o 24 inch Blow Off
Outlets
Outlet of Drains
Ventilator Shafts
FOUR VAULTED FILTERS
EACH 121'4" X 258'0"
Office and Laboratory
Sand Run Entrances
Sand Washing Apparatus
CENTRAL COURT
Regulator House
Pure Water Reservoir 91'0" x 94'0"
Toe of Embankment
Ditch
Erie Canal Slip No 67
48 Inch Steel Conduit to Pumping Station

FIG. 4.



PIPE SYSTEMS
DISTRIBUTION OF RAW WATER, COLLECTION OF PURE WATER, AND WASTE DRAINS.
SCALE
100 FEET
50 METERS
Intake
Pump Well
Chimney
Pumping Station
Venturi Meter
36" Gate
Supply from River
Inlet Pipe
SEDIMENTATION BASIN
600.0'
382.67'
Blow Off
Overflow Manhole
Laboratory
Outlet Pipe
Laid in Concrete
Outlet to River
30" Drain
4" Supply from City
36" By Pass
36" Supply to Filters
FILTER NO. 1
FILTER NO. 2
FILTER NO. 3
FILTER NO. 4
FILTER NO. 5
FILTER NO. 6
FILTER NO. 7
FILTER NO. 8
Division Wall
Inlet
Overflow
Sand Washer
Regulator House
8" Supply
36" from City
Pure Water Pipe
30" Drain in
Pure Water Reservoir
Sand Washer
94.0'
121.4'
258.0'
Pumping Station

FIG. 5.

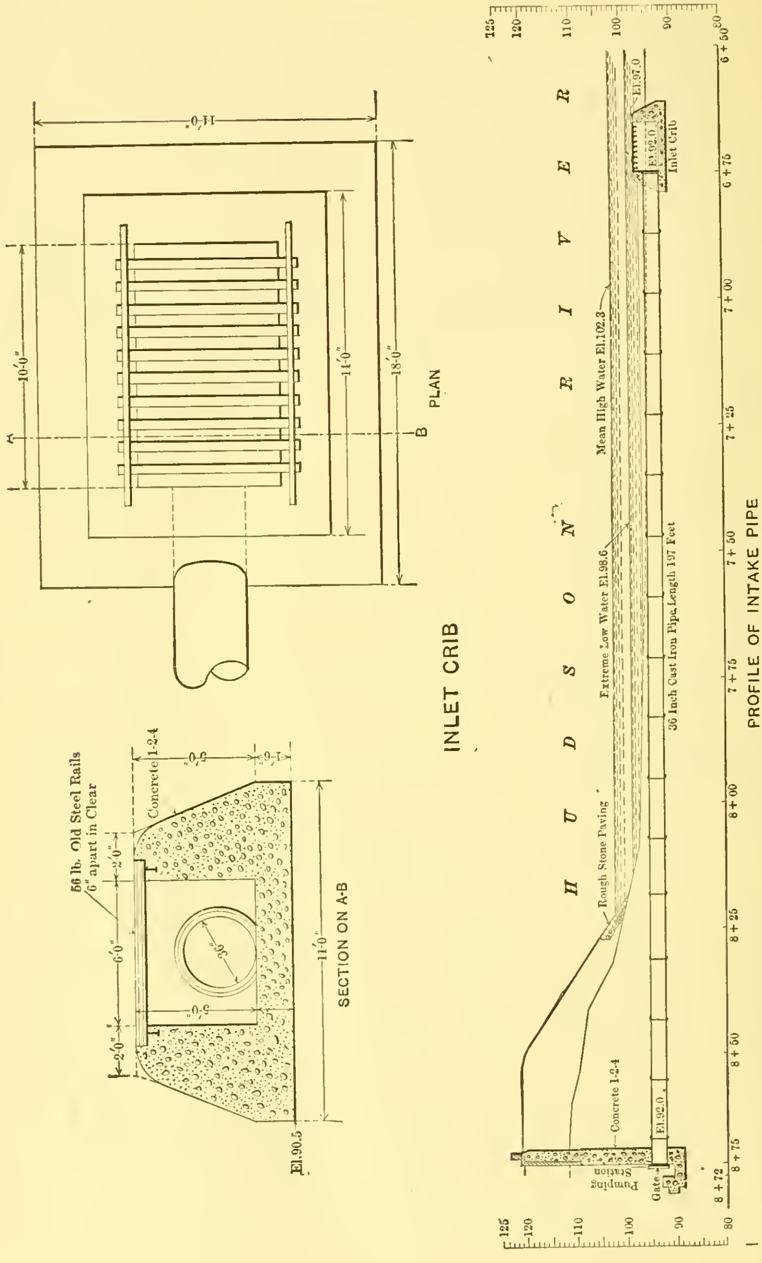
in Figs. 3 to 14, and this description, for the most part, will be limited to those points which are not thus shown.

Intake. — The intake is shown by Fig. 6, and consists of a simple concrete structure in the form of a box, having an open top covered with rails 6 inches apart, and connected below, through a 36-inch pipe, with a well in the pumping station. Before going to the pumps the water passes through a screen with bars 2 inches apart, so arranged as to be raked readily. The rails over the intake and this screen are intended to stop matters which might obstruct the passageways of the pumps, but no attempt is made to stop fish, leaves, or other floating matters which may be in the water. The arrangement, in this respect, is like that of the filter at Lawrence, Mass., where the raw water is not subjected to close screening. There is room, however, to place finer screens in the pump well, should they be found desirable.

Pumps. — The centrifugal pumps have a guaranteed capacity of 16 000 000 gallons per 24 hours against a lift of 18 feet, or 12 000 000 gallons per 24 hours against a lift of 24 feet, corresponding to a water-horse-power, in either case, of 50.5. The ordinary pumping at low water is against the higher lift, and under these conditions either pump can supply the ordinary consumption, the other being held in reserve. The plant is arranged, however, so that if for any reason a large quantity of water is required when only one pump can be used, water can be pumped directly to the filters against the lower head, in which case one pump will deliver a larger quantity, up to 16 000 000 gallons, the full nominal capacity of the plant.

Pumping Station. — The pumping station building, to a point above the highest flood-level, is of massive concrete construction, without openings. Nearly all the machinery is necessarily below this level, and in high water the sluice gates are closed, and the machinery is thus protected from flooding. The superstructure is of pressed brick, with granite trimmings. The general form of the pumping station and the arrangement of the pumping machinery are shown in Fig. 7. A distant view of the building is shown in Fig. 1, Plate IV.

Meter for Raw Water. — Upon leaving the pumping station the water passes through a 36-inch Venturi meter having a throat diameter of 17 inches, the throat area being two ninths of the area of the pipe. This meter records the quantity of water pumped, and is



INLET CRIB

PROFILE OF INTAKE PIPE

FIG. 6.

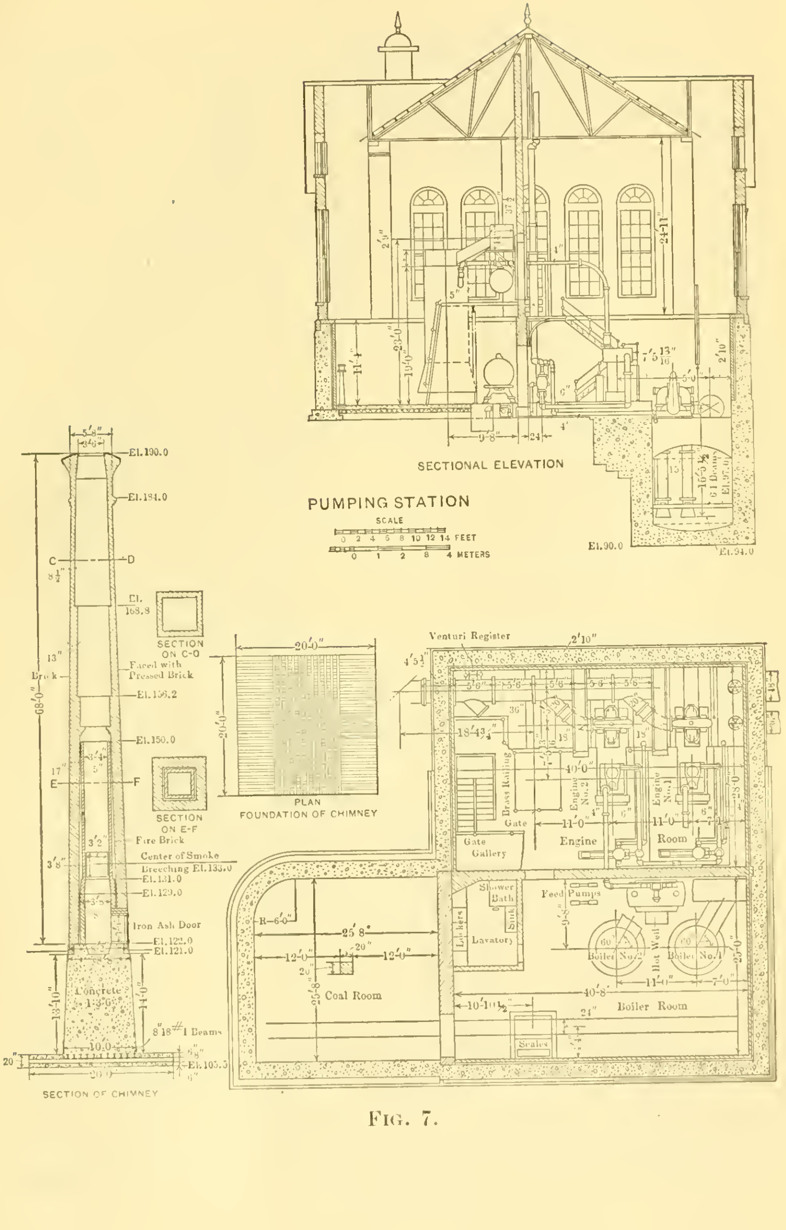

SECTIONAL ELEVATION
PUMPING STATION
SCALE
FEET
METERS
SECTION OF CHIMNEY
SECTION ON C-D
SECTION ON E-F
PLAN
FOUNDATION OF CHIMNEY
Venturi Register
Engine Room
Gate Gallery
Brass Railing
Shower Bath
Lavatory
Lockers
Sink
Feed Pumps
Boiler No. 2
Boiler No. 1
Hot Well
Boiler Room
Coal Room
Scales
Faced with Pressed Brick
Fire Brick
Center of Smoke Breeching El. 133.0
Iron Ash Door
Concrete 1:3:6
I Beams

FIG. 7.

also arranged to show on gages in the pumping station the rate of pumping.

Aeration. — After leaving the meter, the water passes to the sedimentation basin through eleven outlets. These outlets consist of 12-inch pipes on end, the tops of which are 4 feet above the nominal flow line of the sedimentation basin. Each of these outlet pipes is pierced with 296 $\frac{3}{8}$-inch holes extending from 0.5 to 3.5 feet below the top of the pipe. These holes are computed so that when 11 000 000 gallons of water per day are pumped, all the water will pass through the holes, the water in the pipes standing flush with the tops. The water is thus thrown out in 3 256 small streams, and becomes aerated. When a larger quantity is pumped, the excess flows over the tops of the outlet pipes in thin sheets, which are broken by the jets.

Regarding the necessity for aeration, no observations have been taken upon the Hudson River, but, judging from experience with the Merrimac, at Lawrence, where the conditions are in many respects similar, the water is, for the greater part of the year, nearly saturated with oxygen, and aeration is not necessary. During low water in summer, however, there is much less oxygen in the water, and at these times aeration is a distinct advantage. Further, the river water will often have a slight odor, and aeration will tend to remove it. The outlets are so arranged that they can be removed readily, if they are not found necessary.

Sedimentation Basin. — The sedimentation basin has an area of 5 acres and is 9 feet deep. To the overflow, it has a capacity of 14 600 000 gallons, and, to the flow line of the filters, 8 900 000 gallons. There is thus a reserve capacity of 5 700 000 gallons between these limits, and this amount can be drawn upon, without inconvenience, for maintaining the filters in service while the pumps are shut down. This allows a freedom in the operation of the pumps, which would not exist with the water supplied directly to the filters.

The sedimentation basin is built on the river bank, largely above the natural surface of the soil. The sides are embankments made of clay obtained in excavating for the filters, mixed with gravel dredged from the river. These materials were put down in alternate 3-inch layers, wetted, and harrowed, and were rolled with 3-ton grooved rollers on the top of each gravel layer until the gravel was forced down into and thoroughly embedded in the clay. The embankments

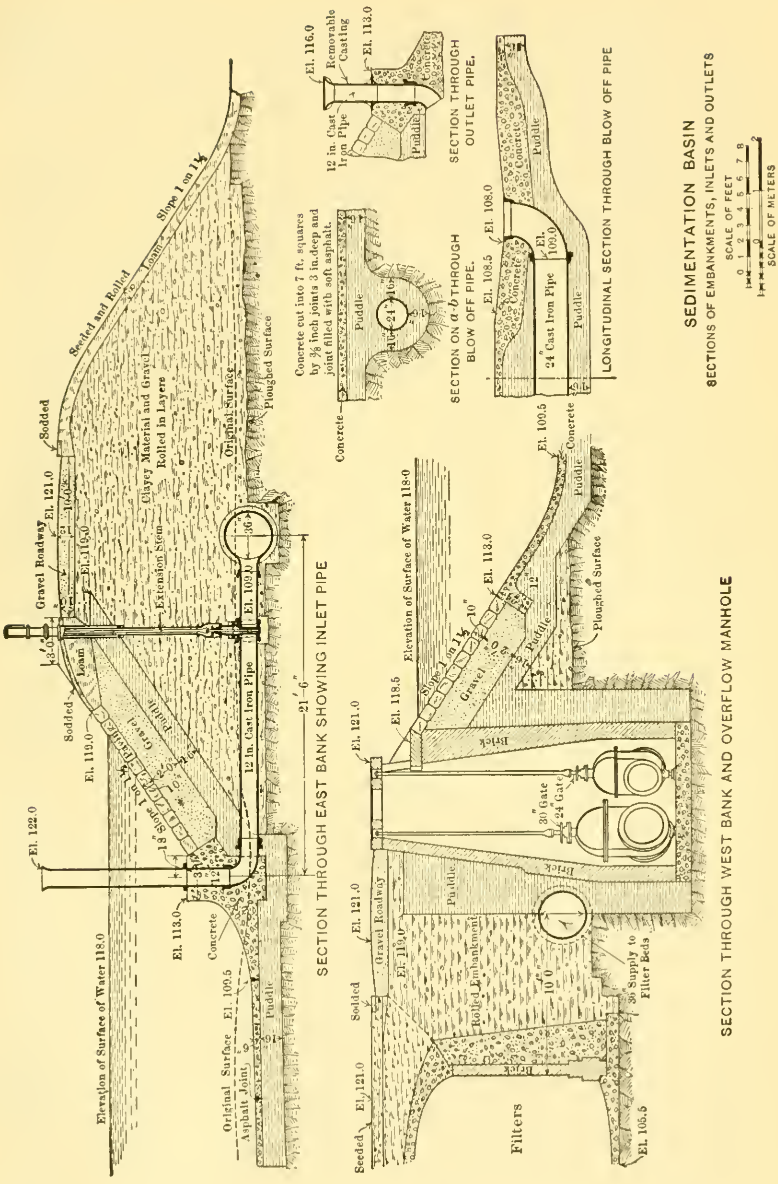

SECTION THROUGH EAST BANK SHOWING INLET PIPE
Elevation of Surface of Water 118.0
El. 122.0
El. 119.0
Sodded
Loam
Gravel Roadway
El. 121.0
El. 119.0
Seeded and Rolled
Slope 1 on 1½
Clayey Material and Gravel Rolled in Layers
Extension Stem
Original Surface
Ploughed Surface
Paving
Gravel
Puddle
Slope 1 on 1½
12 in. Cast Iron Pipe
El. 109.0
El. 113.0
Concrete
El. 109.5
Original Surface
Asphalt Joint
Puddle
21′-6″
SECTION THROUGH WEST BANK AND OVERFLOW MANHOLE
Seeded
El. 121.0
Sodded
El. 121.0
Gravel Roadway
El. 119.0
Rolled Embankment
Puddle
Filters
El. 105.5
Brick
36″ Supply to Filter Beds
El. 121.0
El. 118.5
Elevation of Surface of Water 118.0
Slope 1 on 1½
Gravel
Puddle
El. 113.0
30″ Gate
24″ Gate
Ploughed Surface
El. 109.5
Concrete
Puddle
Concrete cut into 7 ft. squares by ⅜ inch joints 3 in. deep and joint filled with soft asphalt.
Concrete
Puddle
SECTION ON a-b THROUGH BLOW OFF PIPE.
El. 116.0
Removable Casting
El. 113.0
12 in. Cast Iron Pipe
Concrete
Puddle
SECTION THROUGH OUTLET PIPE.
El. 108.5
El. 108.0
El. 109.0
Concrete
24″ Cast Iron Pipe
Puddle
LONGITUDINAL SECTION THROUGH BLOW OFF PIPE
SEDIMENTATION BASIN
SECTIONS OF EMBANKMENTS, INLETS AND OUTLETS
SCALE OF FEET
SCALE OF METERS

FIG. 8.

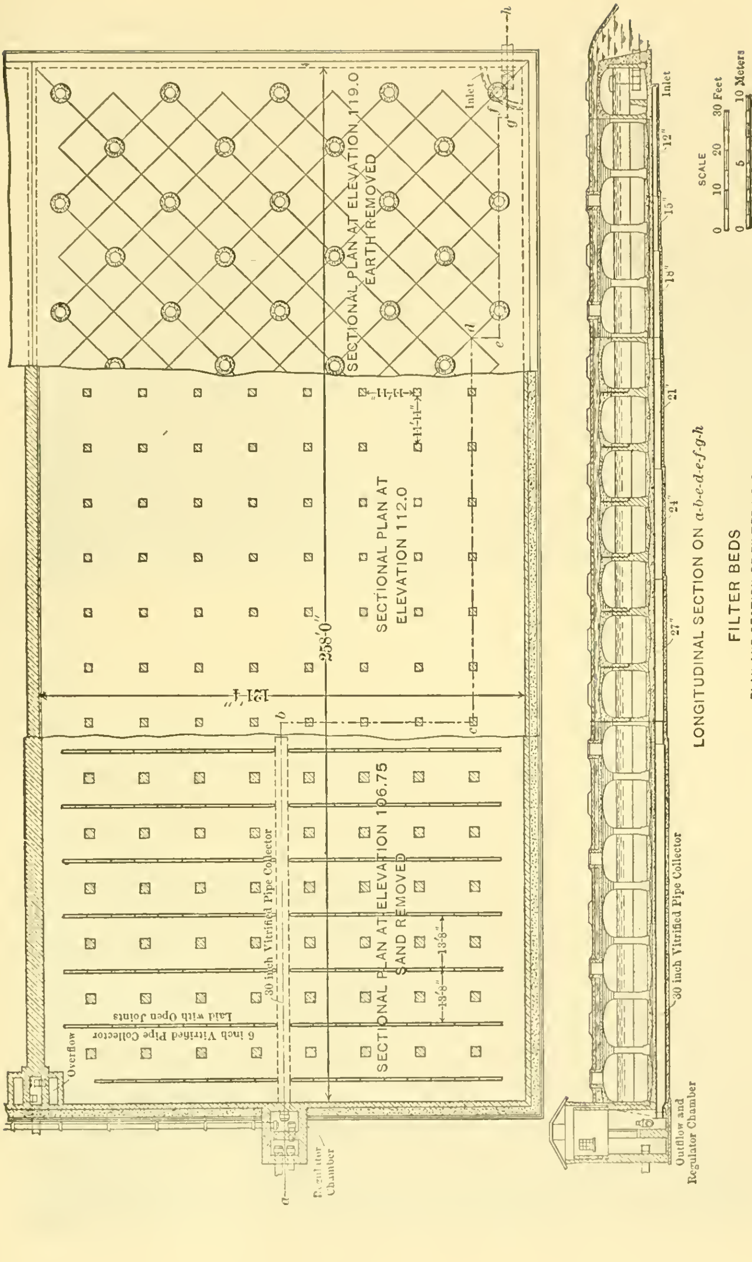
made in this way are extremely solid, stand vertically when cut, are not readily washed, and no leakage through them has appeared at any point. The outsides of the embankments are covered with soil, and the inside and bottom with 16 inches of puddle, which is protected from frost on the sides by a covering of gravel, above which is a rough blue-stone pavement.

The puddle was made by mixing equal volumes of the clay obtained in excavating for the filters, and mixed sand and gravel obtained from the river by dredging. It differed from the material of the embankments only in more thorough mixing, and greater care in placing. The materials were mixed in a pug mill. It was soon found that the best mixing was secured with rather large quantities of water, while the best ramming required that the materials should not be too wet. Accordingly, the materials were mixed wet, given a preliminary ramming, allowing to stand two or three days, and afterwards given the final ramming. The puddle was put down in three layers, and the concrete rested directly upon it. The concrete was put down in blocks about 7 feet square, with $\frac{1}{2}$-inch joints, extending halfway from top to bottom, filled with asphalt. The maximum rate of placing puddle was about 3 000 cubic yards per month.

The water enters the sedimentation basin from eleven inlets along one side and is withdrawn from eleven outlets directly opposite. The inlets and aerating devices previously described bring the water into the basin without current, and evenly distributed along one side. Both inlets and outlets are controlled by gates, so that any irregularities in distribution can be avoided.

The floor of the sedimentation basin is built with even slopes from the toe of each embankment to a sump, the heights of these slopes being 1 foot, whatever their lengths. The sump is connected with a 24-inch pipe leading to a large manhole in which there is a gate through which water can be drawn to empty the basin. There is an overflow from the basin to this manhole, which makes it impossible to fill the basin above the intended level. A section of the embankment about the sedimentation basin and other details are shown in Fig. 8. A view of a portion of the finished basin in use is shown in Fig. 1, Plate IV.

Filters. — The filters are contained in masonry chambers and are covered to protect them against the winters, which are quite severe in Albany. The piers, cross-walls, and linings of the outside walls, entrances, etc., are of vitrified brick. All other masonry is con-



LONGITUDINAL SECTION ON *a-b-c-d-e-f-g-h*

FILTER BEDS

PLAN AND SECTION OF FILTER NO. 2

FIG. 9.

crete. The average depth of excavation for the filters was 4 feet, and the material at the bottom was usually blue or yellow clay.

Floors. — The floors consist of inverted, groined, concrete arches, arranged to distribute the weight of the walls and vaulting over the whole area of the bottom. They were put in in alternate squares running diagonally with the pier lines, as shown in Fig. 1, Plate I.

Walls. — For the outside walls the brick linings, 8 inches thick, were built first to the full height. A certain number of bricks were laid endwise, and projected into the concrete. These occupied about 4% of the area of the wall. Afterwards, wooden forms were put up on the outside, and the concrete backing was filled in. Sections of the walls are shown in Fig. 10. The arrangement of the projecting brick is shown in Fig. 2, Plate II, which also shows the outside forms for the concrete wall in the distance.

Vaulting. — The concrete vaulting was placed on wooden centers supported on wedges which could be knocked out after the concrete had set, so that the centers came down readily, and could be moved forward and used again. Some of them were used four or five times in the course of the work, the only repairs necessary being the patching of the lagging, and were in good order at the end of the work. The vaulting was designed with a clear span of 12 feet, a rise of 2½ feet, and a thickness of 6 inches at the crown, but the clear span was reduced to 11 feet 11 inches to fit the sizes of the bricks in the piers. It was put in in squares, the joints being on the crowns of the arches parallel to the lines of the piers, and each pier being the center of one square. The manholes are in alternate sections, and are of concrete, built in steel forms with castings at the tops, securely jointed to the concrete.

Above the vaulting there are 2 feet of earth and soil, grassed on top. The tops of the manholes are 6 inches above the soil to prevent rain water from entering them. The drainage of the soil is effected by a depression of the vaulting over each pier, partially filled with gravel and sand, from which water is removed by a 2-inch tile drain going down the center of the pier and discharging through its side just above the top of the sand in the filter. The saving in cost by this arrangement was considerable, as the cost of the drains was much less than that of the concrete which would have been necessary to fill the areas over the piers had any other system been adopted. Further, the water entering in this way is as good as any

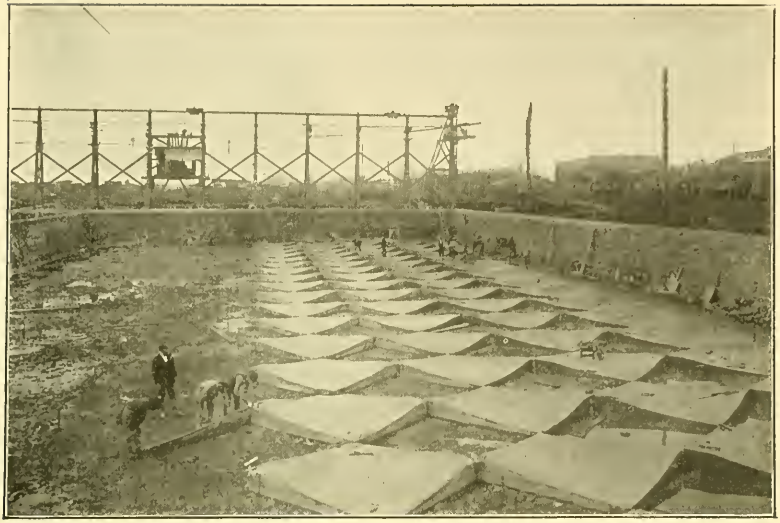


FIG. 1.—PLACING THE FLOOR OF A FILTER.

FIG. 2.—BUILDING THE BRICK PIERS.

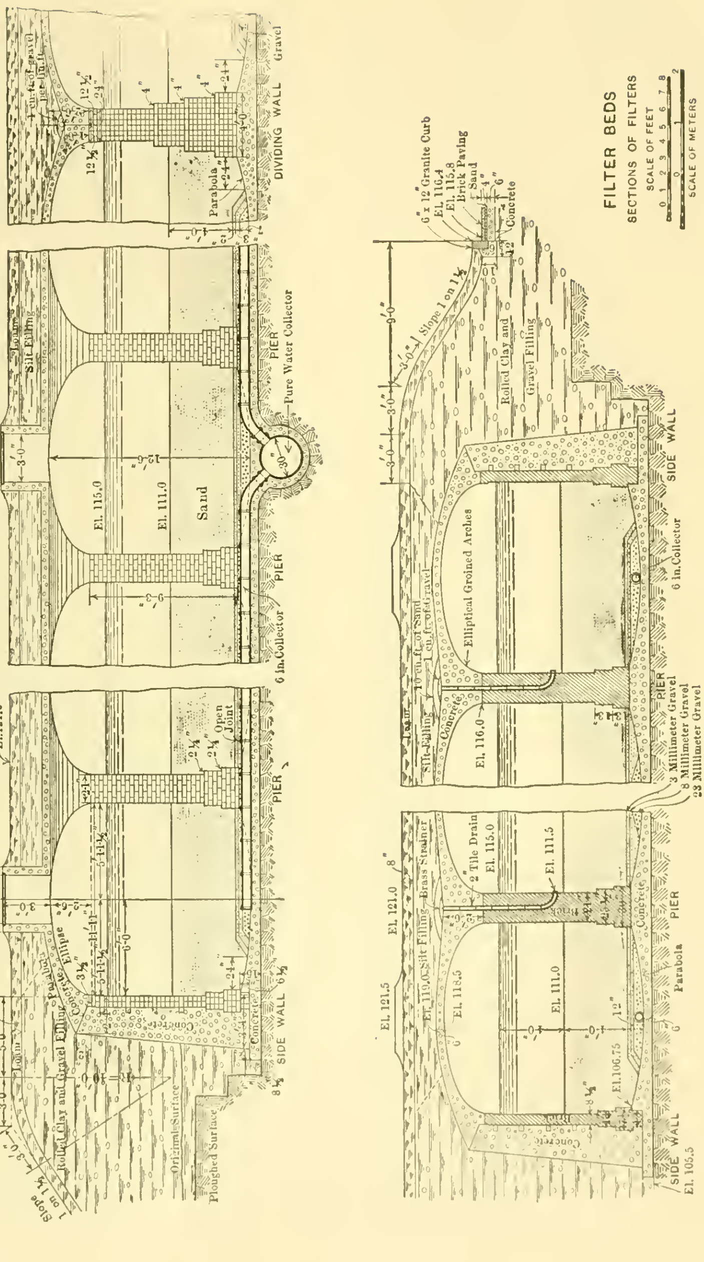

FILTER BEDS
SECTIONS OF FILTERS
SCALE OF FEET
SCALE OF METERS
2 Sheet Steel Covers
2 Inch Air Space
El. 121.5
El. 121.0
El. 115.0
El. 111.0
Sand
PIER
SIDE WALL
DIVIDING WALL
Gravel
Pure Water Collector
6 in. Collector
Open Joint
Parabola
Ellipse
Concrete
Silt Filling
Loam
Rolled Clay and Gravel Filling
Original Surface
Ploughed Surface
Slope 1 on 1½
6" x 12" Granite Curb
El. 116.4
El. 115.8
Brick Paving
Sand
Concrete
Rolled Clay and Gravel Filling
Elliptical Groined Arches
10 cu. ft. of Sand
1 cu. ft. of Gravel
El. 116.0
3 Millimeter Gravel
8 Millimeter Gravel
23 Millimeter Gravel
El. 119.0
Brass Strainer
2" Tile Drain
El. 111.5
El. 118.5
El. 106.75
El. 105.5
Brick

FIG. 10.

water available, and there is every reason for adding it to the supply before it passes through the filters. Sections of the vaulting are shown in Fig. 10. Plate II, Fig. 1 gives a general view of the vaulting at various stages. The finished vaulting is shown from beneath in Plate III, Figs. 1 and 2.

In order to provide ready access to each filter, a part of the vaulting near one side is elevated and made cylindrical in shape, making an inclined runway from the sand level to a door, the threshold of which is 6 inches above the level of the overflow. This sand-run is provided with permanent timber runways and with secure doors.

The vaulting is similar, in many respects, to that of the covered filters at Ashland, Wis., and at Somersworth, N. H., but differs from that vaulting in that it is entirely of concrete, instead of brick backed by concrete.

Underdrains. — The main underdrains for removing the filtered water are of vitrified pipe surrounded by concrete, and are entirely below the floors of the filters. They were put in before the construction of the filters was commenced, and the concrete surrounding them was brought to the plane of the bottom of the foundations, so that when the floor was built it went over them continuously, without breaking in any way the line of inverted arches. This arrangement was adopted because the drains would have been in the way if they had been placed entirely above the floor, and if any part of the drain had been placed in the normal floor-span it would have reduced the strength of the inverted arches, and would itself have been liable to breakage by their pressure. As the surrounding material is clay or tight rock, no danger of loss of water by seepage can result from this arrangement.

The main collectors are 30-inch vitrified pipes, reduced by castings to 20 inches at the outlets, and the effluent from each filter passes through a 20-inch gate. The underdrains are made much larger than would ordinarily be required for carrying the quantities of water involved. The reason for this is that after a filter has just been scraped, the frictional loss in passing the sand is very slight. If the friction of the underdrainage system is not kept very low, there will be so much loss of head that when a filter is started the pull exerted at remote parts of the filter will be less than at points near the outlet, and thus the parts near the outlet will operate at rates which are too high, while the more remote parts will hardly filter at all, and the resulting purification is less than it should be.

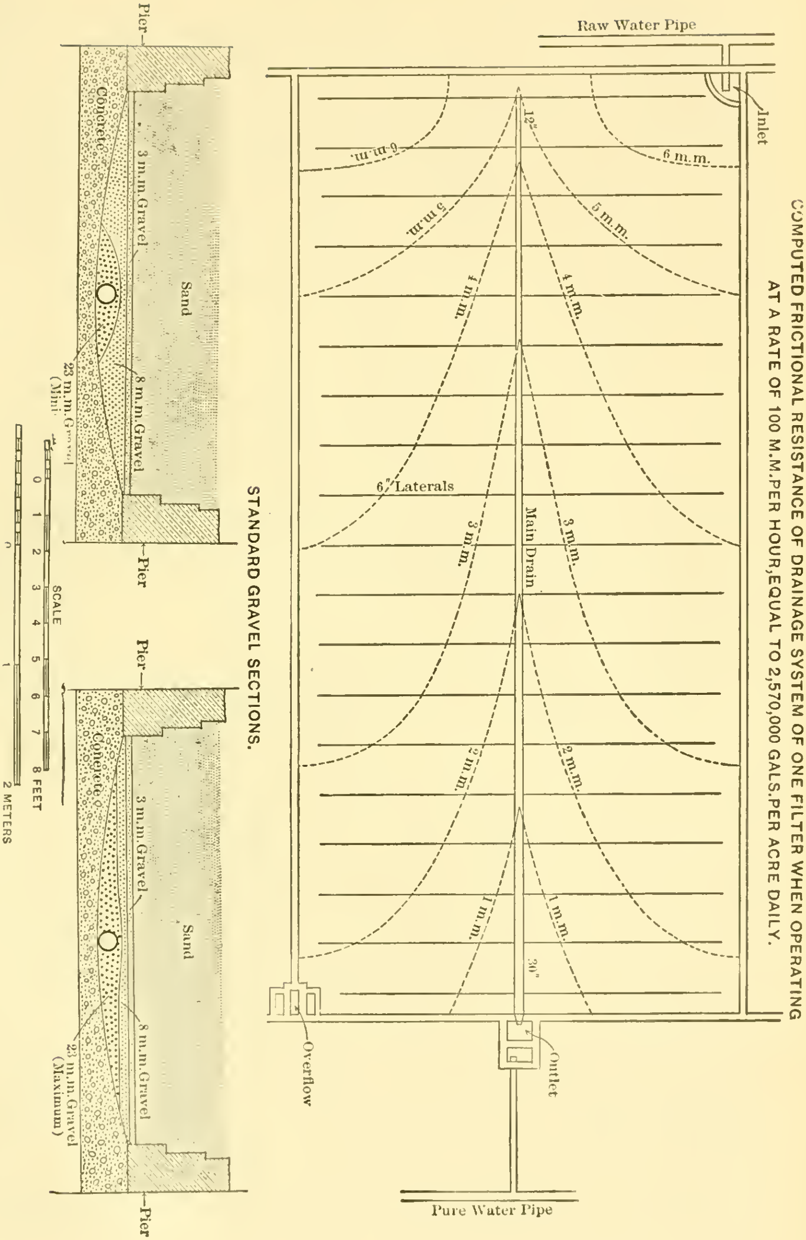

COMPUTED FRICTIONAL RESISTANCE OF DRAINAGE SYSTEM OF ONE FILTER WHEN OPERATING
AT A RATE OF 100 M.M. PER HOUR, EQUAL TO 2,570,000 GALS. PER ACRE DAILY.
Raw Water Pipe
Inlet
12"
6 m.m.
5 m.m.
4 m.m.
3 m.m.
2 m.m.
1 m.m.
6" Laterals
Main Drain
30"
Overflow
Outlet
Pure Water Pipe
STANDARD GRAVEL SECTIONS.
Pier
Concrete
3 m.m. Gravel
Sand
8 m.m. Gravel
23 m.m. Gravel
(Maximum)
SCALE
0 1 2 3 4 5 6 7 8 FEET
0 1 2 METERS

FIG. 11.

The underdrainage system is so designed that, when starting a filter after cleaning, the friction of the sand is about 50 mm. at a rate of 3 000 000 gallons per acre daily, and the loss of head in the underdrainage system is estimated at 10 mm. This very low friction, which is necessary, is obtained by the use of ample sizes for the underdrains and low velocities in them. In the outlet and measuring devices moderate losses of head are not objectionable, and these pipes and connections are, therefore, smaller than the main underdrains.

Connections with the drain are made through thirty-eight 6-inch outlets in each filter, passing through the floor and connecting with 6-inch lateral drains running the whole width of the filter. These drains were made with pipes having one side of the bell cut off, so that they would lie flat on the floor and make concentric joints, without having to be wedged. They were laid with a space of about 1 inch between the barrels, leaving a large opening for the admission of water from the gravel. The general arrangement of the drainage system is shown in Fig. 5. Other details are shown in Figs. 9 and 10, while the computed frictional resistance of one filter is shown in Fig. 11.

Filter Gravel. — The gravel surrounding the underdrains is of three grades. The material was obtained from the river-bed by dredging, and was of the same stock as that used for preparing ballast for the concrete. It was separated and cleaned by a special, cylindrical, revolving screen. The coarsest grade of gravel was that which would not pass round holes 1 inch in diameter, and free from stones more than about 2 inches in diameter. At first it was required to pass a screen with holes 2 inches in diameter, but this screen removed many stones which it was desired to retain, and the screen was afterwards changed to have holes 3 inches in diameter. The intermediate grades of gravel passed the 1-inch holes, and were retained by a screen with round holes $\frac{3}{8}$ inch in diameter. The finest gravel passed the above screens and was retained by a screen with round holes $\frac{3}{16}$ inch in diameter. The gravel was washed, until free from sand and dirt, by water played upon it during the process of screening, and it was afterwards taken over screens in the chutes where it was separated from the dirty water, and, when necessary, further quantities of water were played upon it at these points.

The average mechanical analyses of the three grades of gravel are shown by Fig. 13. Their effective sizes were 23, 8, and 3 mm.,

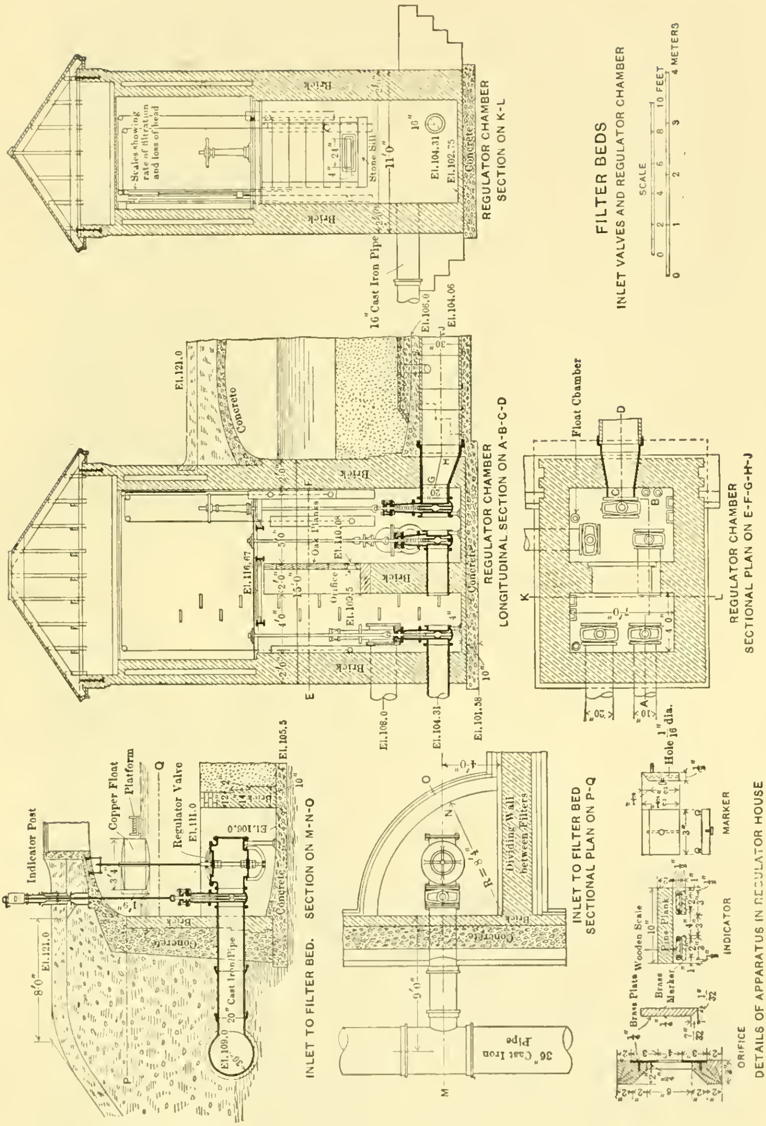

FILTER BEDS
INLET VALVES AND REGULATOR CHAMBER
REGULATOR CHAMBER
SECTION ON K-L
REGULATOR CHAMBER
LONGITUDINAL SECTION ON A-B-C-D
REGULATOR CHAMBER
SECTIONAL PLAN ON E-F-G-H-J
INLET TO FILTER BED. SECTION ON M-N-O
INLET TO FILTER BED
SECTIONAL PLAN ON P-Q
DETAILS OF APPARATUS IN REGULATOR HOUSE
ORIFICE
INDICATOR
MARKER
Indicator Post
Copper Float
Platform
Regulator Valve
20" Cast Iron Pipe
36" Cast Iron Pipe
16" Cast Iron Pipe
Dividing Wall between Filters
Float Chamber
Scales showing rate of filtration and loss of head
Stone Sill
Oak Planks
Orifice
Concrete
Brick
Wooden Scale
Brass Plate
Brass Marker
Pine Plank

FIG. 12.

respectively, and, for convenience, they are designated by these numbers. The average uniformity coefficient for each grade was about 1.8.

The 23-mm. gravel entirely surrounded the 6-inch pipe drains, and was carried slightly above their tops. In some cases it was used to cover nearly the whole of the floor, but this was not insisted upon.

The 8-mm. gravel was obtained in larger quantity than the other sizes, and was used to fill all spaces up to a plane 2½ inches below the finished surface of the gravel, this layer being about 2 inches thick over the tops of the drains, and somewhat thicker elsewhere.

The 3-mm. gravel was then applied in a layer 2½ inches deep, and the surface leveled. The grades for the two upper gravel layers were shown directly by the joints in the brick work of the piers.

The form of construction made it best to put a lateral drain in each section, or 13 feet 8 inches apart on centers. The drain itself occupies 7 inches, and the longest course which water has to pass in the gravel, in any event, is about 6½ feet. This distance is so short that the frictional resistance of the filtered water in passing through the gravel is extremely small, and, therefore, it was possible to vary the gravel sections somewhat according to the relative amounts of gravel of the several grades obtained in screening, without detriment to the work. The thickness of the 3-mm. gravel was varied between 2 and 2½ inches, according to the supply available, and similar variations were made in the other grades ; but the finished surface of the gravel was always kept at the same elevation. Typical sections of the arrangements of the gravels are shown in Figs. 10 and 11, and in Fig. 1, Plate III. The greatest rate at which gravel was obtained and placed was about 1 500 cubic yards per month.

Filter Sand. — The preliminary estimates of cost were based upon the use of filter sand from a bank near the filter site. Further examination showed that this sand contained a considerable quantity of lime, and it was found by experiment with a small filter constructed for that purpose that the use of this sand would harden the water by about 2 parts in 100 000, and the amount of lime contained in the sand, namely, about 7%, was sufficient to continue this hardening action for a considerable number of years. This was regarded as a serious objection to its use, and the specifications were drawn limiting the amount of lime in the sand, thus excluding all of the local bank sands. The river sands which were used were nearly free from lime, and in the end the sand as secured was probably not only free

Fig. 1. — General View of Vaulting, under Construction.

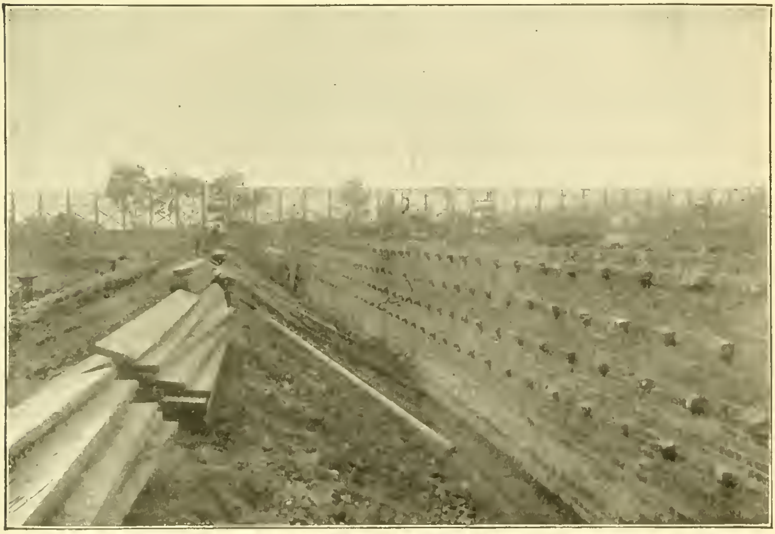


Fig. 2. — Outside Wall, ready for Concrete Backing.

from lime, but more satisfactory in other ways, and also cheaper than the bank sand would have been.

The specifications of the filter sand require that —

"The filter sand shall be clean river, beach or bank sand, with either sharp or rounded grains. It shall be entirely free from clay, dust or organic impurities, and shall, if necessary, be washed to remove such materials from it. The grains shall, all of them, be of hard material, which will not disintegrate, and shall be of the following diameters: Not more than 1% by weight less than 0.13 mm., nor more than 10% less than 0.27 mm.; at least 10% by weight shall be less than 0.36 mm. and at least 70%, by weight, shall be less than 1 mm., and no particles shall be more than 5 mm. in diameter. The diameters of the sand grains will be computed as the diameters of spheres of equal volume. The sand shall not contain more than 2%, by weight, of lime and magnesia taken together and calculated as carbonates."

With the river sand and the method of handling adopted by the contractors, it was possible to control the quality of the sand, so that the specifications were complied with. In the lower layers of two of the filters a little sand was allowed which contained a few particles above 5 mm. in diameter. The screens were adjusted afterwards so that the largest remaining particles were less than 4 mm. in diameter. The filter sand has effective sizes of from 0.29 to 0.32 mm., averaging 0.31; and uniformity coefficients from 2.2 to 2.5, averaging 2.3. Its mechanical composition is shown by the diagram, Fig. 13.

The sand and also the gravel were delivered in the filters through the manholes, temporary plank roadways being built for that purpose. Trucks carrying 1½ cubic yards, with a pair of horses, were driven over the vaulting in all directions, without hesitation and without damage to it. The sand was dumped on plank platforms constructed below. A record was kept of all the planks used for this purpose, and they were required to be taken up in the presence of inspectors afterwards to prevent the possibility of leaving any of them in the filter. This arrangement necessitated working over all the sand underneath the points of dumping, and it thereby became loosened from the excessive packing caused by dumping it from a height. The sand was deposited in three horizontal layers, so that, if by accident sand of unusual quality was placed at any point, the same kind of sand would not extend from top to bottom. The method of placing the sand in layers is shown in Fig. 1, Plate III,

which also shows the gravel layers and a lateral underdrain; while a completed filter with the sand smoothed ready for use is shown in Fig. 2, Plate III.

Sand-washing Apparatus. — Most of the suspended matters in the filtered water are held by the top layer of sand, and this layer is removed from time to time. The dirty sand is washed, and eventually replaced in the filters. Two ejector sand-washing machines, shown in Fig. 14, are provided at convenient places between the filters. In them the dirty sand is mixed with water, and is thrown up by an ejector, after which it runs through a chute into a receptacle, from which it is again lifted by another ejector. It passes in all through five ejectors, part of the dirty water being wasted each time. The sand is finally collected from the last ejector, where it is allowed to deposit from the water.

Sand washers of this kind have been used for many years by some of the London water companies, and more recently at Hamburg; and also at Lawrence and Poughkeepsie in this country.

The entire central court between the filters and about the sand washers, shown in Fig. 2, Plate IV, is paved with brick upon a concrete foundation, and affords a convenient space for handling and storing sand.

Inlets to Filters. — Water is admitted to each filter through a 20-inch pipe from a pipe system connecting with the sedimentation basin. Just inside of the filter wall is placed a standard gate and beyond that a balanced valve connected with an adjustable float to shut off the water when it reaches the desired height on the filter (Fig. 12). These valves and floats were constructed from special designs, and are similar in principle to valves used for the same purpose in the Berlin water filters.

Overflows. — Each filter is provided with an overflow, so arranged that it cannot be closed, which prevents the water level from exceeding a fixed limit in case the balanced valve fails to act. An outlet is also provided near the sand-run, so that unfiltered water can be removed quickly from the surface of the filter, should it be necessary, to facilitate cleaning.

Filter Outlets. — The outlet of each filter is through a 20-inch gate controlled by a standard graduated to show the exact distance the gate is open. The water rises in a chamber and flows through an orifice in a brass plate 4 by 24 inches, the center of which is 1 foot below the level of the sand line. At the normal rate of filtration,

3 000 000 gallons per acre daily, 1 foot of head is required to force the water through the orifice. With other rates the head increases or decreases approximately as the square of the rate and forms a measure of it. With water standing in the lower chamber, so that the orifice is submerged, it is assumed that the same rate will be obtained with a given difference in level between the water on the two sides of the orifice, as from an equal head above the center of the orifice when discharging into air. The general arrangement of the gate-houses, including the gates for wasting the effluent to the river, for filling filters with filtered water from below, etc., is shown in Fig. 12, while outside views of gate-houses are shown in Fig. 2, Plate I, and Fig. 2, Plate IV.

Measurement of Effluent. — In order to show the rate of filtration two floats are connected with the water on the two sides of the orifice. These floats are counterbalanced; one carries a graduated scale and the other a marker which moves in front of the scale and shows the rate of filtration corresponding to the difference in level of the water on the two sides.

When the water in the lower chamber falls below the center of the orifice, the water in the float chamber is, nevertheless, maintained at this level. This is accomplished by making the lower part of the tube water-tight, with openings just at the desired level, so that when the water falls below this point in the outer chamber it does not fall in the float chamber. To prevent the loss of water in the float chamber by evaporation, or from other causes, a lead pipe is brought from the other chamber and supplies a driblet of water to it constantly; this overflows through the openings, and maintains the water level at precisely the desired point. The floats thus indicate the difference in water level on the two sides of the orifice whenever the water in the lower chamber is above the center of the orifice; otherwise, they indicate the height of water in the upper chamber above the center of the orifice, regardless of the water level in the lower chamber. The scale is graduated to show the rates of filtration in millions of gallons per acre of filtering area. In computing this scale the area of the filters is taken as 0.7 acre, and the coefficient of discharge as 0.61.

At the ordinary rates of filtration the errors introduced by the different conditions under which the orifice operates will rarely amount to as much as 100 000 gallons per acre daily, or one thirtieth of the ordinary rate of filtration. Usually they are much less than

this. The apparatus thus shows directly, and with substantial accuracy, the rate of filtration under all conditions.

Measurement of Loss of Head. — Two other floats with similar connections show the difference in level between the water standing on the filter and the water in the main drain pipe back of the gate, or in other words, the frictional resistance of the filter, including the drains. This is commonly called the loss of head, and increases from 0.2 foot or less, with a perfectly clean filter, to 4 feet, with the filter ready for cleaning. When the loss of head exceeds 4 feet the rate of filtration cannot be maintained at 3 000 000 gallons per acre daily with the outlet devices provided, and, in order to maintain the rate, the filter must be cleaned.

The outlets of the filters are connected in pairs, so that filtered water can be used for filling the underdrains and sand of the filters from below prior to starting, thus avoiding the disturbance which results from bringing dirty water upon the sand of a filter not filled with water.

Laboratory Building.—The scientific control of the filters is regarded as one of the essentials to the best results, and to provide for this there is a laboratory building at one end of the central court between the filters and close to the sedimentation basin, supplied with the necessary equipment for full bacterial examinations, and also with facilities for observing the colors and turbidities of raw and filtered waters, and for making such chemical examinations as may be necessary. This building also provides a comfortable office, dark room and storage room for tools, etc., used in the work.

Pure-water Reservoir. — A small pure-water reservoir, 94 feet square, and holding about 600 000 gallons, is provided at the filter plant. The construction is similar to that of the filters, but the shapes of the piers and vaulting were changed slightly, as there was no necessity for the ledges about the bottoms of the piers and walls; while provision is made for taking the rain water, falling upon the vaulting above, to the nearest filters instead of allowing it to enter the reservoir. The floor and roof of the reservoir are at the same levels as those of the filters.

Pure-water Conduit. — The filtered water is taken from the pure-water reservoir to the present pumping station through 7 913 feet of 48-inch pipe. For 5 450 feet the pipe is laid under the Erie Canal, and for 1 837 feet through Montgomery Street, with an average cut of 22 feet. The pipe is not under pressure, and is made of mild open-hearth steel plates, $\frac{5}{16}$ inch thick.

Fig. 1.—Interior of a Filter: Drain, Gravel and Sand Layers.

Fig. 2.—Interior of a Filter, ready for Use.

Concrete Backing. — Pipe of this thickness is not stiff enough to withstand the earth pressures in the deep cut in Montgomery Street, without being badly deformed, and is not heavy enough to be safe from the danger of floating in the canal, should the water be removed from the pipe for any reason. Concrete was therefore used to support the sides of the pipe in the deep cut and to weight it under the canal. The amount of concrete required for these purposes was considerable, and the Board decided to use a further amount in order to surround the pipe entirely. This makes a concrete pipe with a minimum thickness of 6 inches outside of the steel pipe for practically the whole distance, capable of supporting the earth, and able itself to serve as a conduit even if the steel pipe should be removed entirely, although in that case it would not be thoroughly water-tight. For 567 feet on hard clay bottom, the concrete on the bottom was omitted, the natural material being probably equivalent to the concrete. For about 300 feet at the upper end, in shallow cut and where the pipe is readily accessible, the concrete was also omitted.

Coating. — The pipe was coated by dipping in asphalt, and after calking tight on the inside, all imperfections in the coating, due to calking or otherwise, were covered with melted asphalt in connection with a naphtha lamp. Where the spots were not too large the asphalt on the sides came together when softened by the flame and covered the spot completely without the addition of new material. Where the uncovered patches were large this was not possible. The place was first heated, then melted asphalt was applied and thoroughly heated and melted until it incorporated itself with the old asphalt on the edges.

The greatest difficulty was experienced in repairing breaks in the coating directly on the bottom of the pipe; although these were not serious, owing to the fact that all men who worked therein were required to wear rubbers, and thus the damage done to the coating was slight. Repairs were made by building dams of cotton waste on each side of the defective place and sponging out the water, after which the plates could be heated by a naphtha lamp and repaired in the usual way.

Brick Work. — All the brick work, except that in the superstructures, was of vitrified paving brick. This brick was not specified, but the specifications required brick absorbing not more than 12% of water by weight. The local brick-makers were unwilling to take the

trouble to make brick hard enough to meet this requirement, and the contractors decided finally to use a second-quality paving brick. With this, the absorption ranged from 1 to 11%, and averaged 4% by weight.

Cracks. — With cold weather, some of the joints in the concrete vaulting opened slightly, indicating the absence of arch action, but no cracks in the blocks have been observed at any point. A few cracks appeared in the walls, none of which was of serious consequence.

CAPACITY OF PLANT AND MEANS OF REGULATION.

The various filters have effective filtering areas of from 0.702 to 0.704 acre, depending upon slight differences in the thickness of the walls in different places. For the purpose of computation, the area of each filter is taken at 0.7 acre. The normal rate of filtration is taken as 3 000 000 gallons per acre daily, at which rate each filter will yield 2 100 000 gallons daily, and, with one filter out of use for the purpose of being cleaned, seven filters normally in use will yield 14 700 000 gallons. The entrances and outlets are all made of sufficient size, so that rates 50% greater than the foregoing are possible. The capacities of the intake, pumping station, and piping are such as to supply any quantity of water which the filters can take, up to an extreme maximum of 25 000 000 gallons in 24 hours. The pure-water conduit from the filters to Quackenbush Street is nominally rated at 25 000 000 gallons per 24 hours, after it has become old and somewhat tuberculated. In its present excellent condition it will carry a larger quantity.

At the pumping station at Quackenbush Street there are three Allis pumps, each capable of lifting 5 000 000 gallons per 24 hours. In addition to the above there are the old reserve pumps with a nominal capacity of 10 000 000 gallons per 24 hours, which can be used if necessary, but which require so much coal that they are seldom used. For practical purposes the 15 000 000 gallons represents the pumping capacity of this station and also the capacity of the filters, but the arrangements are such that in case of emergency the supply can be increased to 20 000 000 or even 25 000 000 gallons for a short time.

The water is pumped through rising mains to reservoirs holding 37 000 000 gallons, not including the Tivoli low-service reservoir, which is usually supplied from gravity sources. The reservoir capacity is such that the pumping can be suspended at Quackenbush Street for considerable periods if necessary, and in practice it has

been suspended at certain times, especially on Sundays. The amount of water required is also somewhat irregular. The drainage areas supplying the gravity reservoirs are much larger, relatively, than the reservoirs, and at flood periods the volume of the gravity supply is much greater than that which can be drawn in dry weather. Thus it happens that, at certain seasons of the year, the amount of water to be pumped is but a fraction of the nominal capacity of the pumps, and at these times it is possible to shut the pumps down for greater lengths of time.

MECHANICAL COMPOSITION OF FILTER SAND AND GRAVELS.

(ARROWS SHOW REQUIREMENT OF SPECIFICATION)

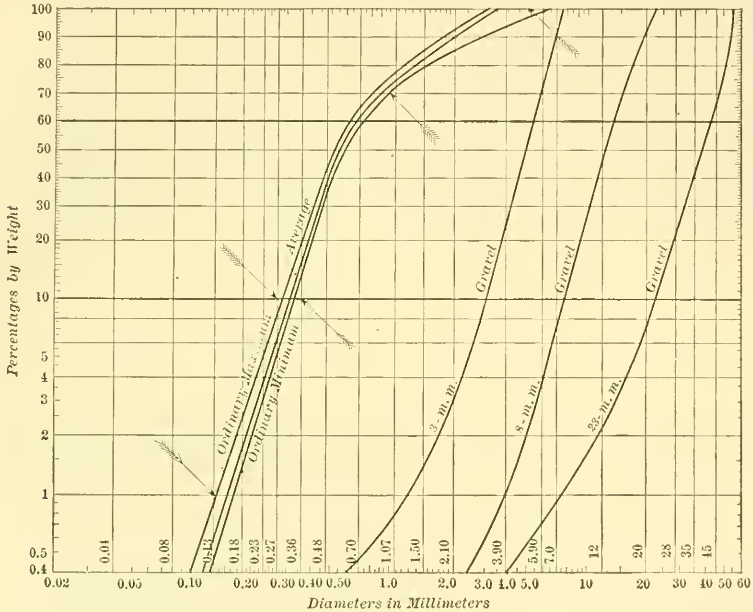


FIG. 13.

Capacity of Pure-water Reservoir. — The storage capacity provided between the filters and the Quackenbush Street pumps is comparatively small, namely, 600 000 gallons, or one hour's supply at the full nominal rate. A larger basin, holding as much as one third or one half of a day's supply, would be in many respects desirable in this position, but the conditions were such as to make it practically impossible. The bottom of the reservoir could not be put lower without deepening and increasing greatly the expense of the conduit line. On the other hand, the flow line of the reservoir could not be

raised without raising the level of the filters, which was hardly possible upon the site selected. The available depth was thus limited between very narrow bounds, and to secure a large capacity would have necessitated a very large area, and consequently a great expense. Under these circumstances, and especially in view of the abundant storage capacity for filtered water in the distributing reservoirs, it was not deemed necessary to secure a large storage, and only so much was provided as would allow the pumps to be started at the convenience of the engineer, and give a reasonable length of time for the filters to be brought into operation. For this the pure-water reservoir is ample, but it is not enough to balance any continued fluctuations in the rate of pumping.

Method of Regulating and Changing the Rate of Filtration. — With all the Allis pumps running at their nominal capacity, the quantity of water required will just about equal the normal capacity of the filters. When only one or two pumps are running, the rate of filtration can be reduced. With the plant operating up to its full capacity, the water level in the pure-water reservoir will be below the level of the standard orifices in the filter outlets. When the rate of pumping is reduced, if no change is made in the gates controlling the filter outlets, the water will gradually rise in the pure-water reservoir and in the various regulator chambers, and will submerge the orifices and gradually reduce the head on the filters, and consequently the rates of filtration, until those rates equal the quantity pumped. In case the pumping is stopped altogether, the filters will keep on delivering at gradually reduced rates until the water level in the pure-water reservoir reaches that of the water on the filters.

When the pumps are started up, after such stoppage or reduced rate of pumping, the water levels in the pure-water reservoir and in the gate chambers will be lowered gradually, and the filters will start to operate at first with extremely low rates which will increase gradually until the water is depressed below the orifices, when they will again reach the rates at which they were last set. The regulators during all this time will show the rate of filtration on each filter, and, if any inequalities occur which demand correction, the gates on the various outlets can be adjusted accordingly.

The arrangement, in this respect, combines some of the features of the English and German plants. In the English plants the filters are usually connected directly with the clear-water basin, and that in turn with the pumps, and the speed of filtration is required to respond

FIG. 1.—SEDIMENTATION BASIN, PUMPING STATION, AND OUTLETS.

FIG. 2.—CENTRAL COURT, SHOWING SAND WASHER, DIRTY SAND, ETC.

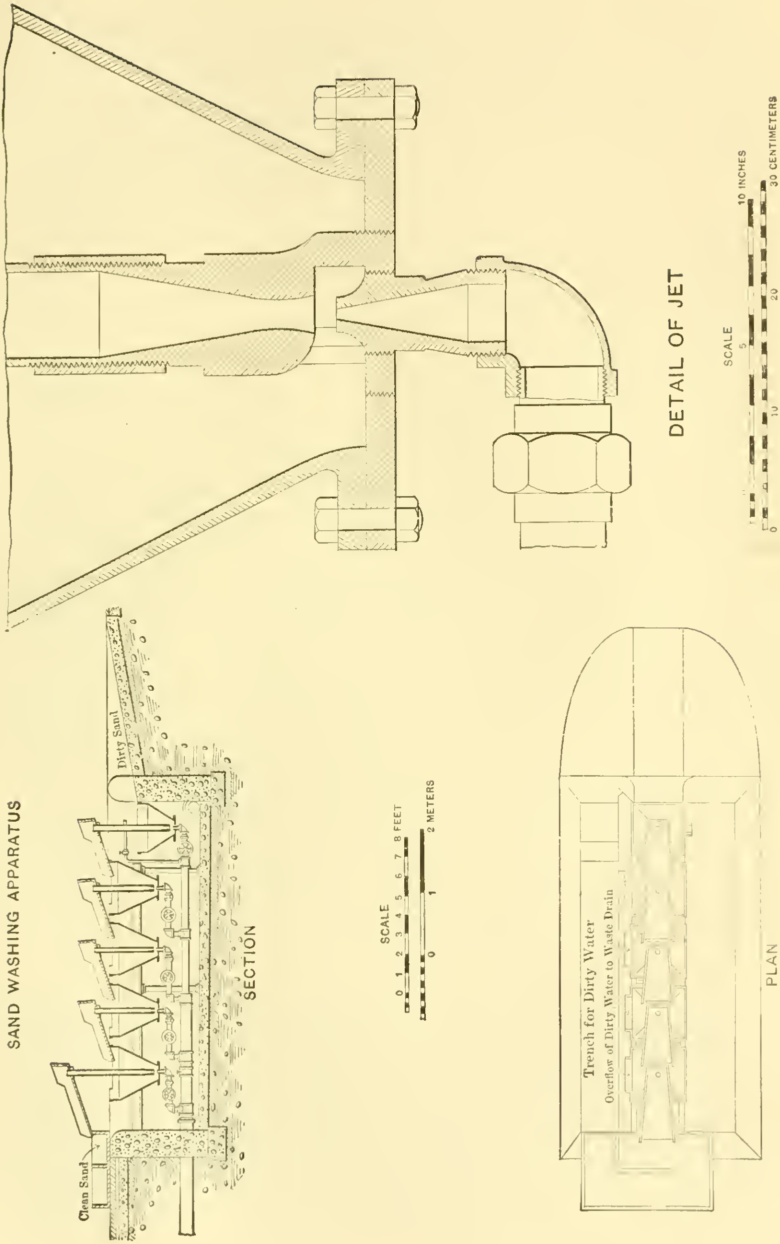

DETAIL OF JET
SCALE
10 INCHES
30 CENTIMETERS
SAND WASHING APPARATUS
Clean Sand
Dirty Sand
SECTION
SCALE
8 FEET
2 METERS
Trench for Dirty Water
Overflow of Dirty Water to Waste Drain
PLAN

FIG. 14.

to the speed of the pumps, increasing and decreasing with it, being regulated at all times by the height of water in the pure-water reservoir. This arrangement has been subject to severe criticism, because the rate of filtration fluctuates with the consumption, and especially because the rates of filtration obtained simultaneously in different filters may be different. There was no way to determine at what rate any individual filter was working, and there was always a tendency for a freshly scraped filter to operate much more rapidly than those which had not been scraped for some time.

This led to the procedure, first formulated by the Commission of German Water Works Engineers in 1894, and provided for in most of the German works built or remodeled since that time, of providing pure-water storage sufficient in amount to make the rate of filtration entirely independent of the operation of the pumps. Each filter was to be controlled by itself, be independent of the others, and deliver its water into a pure-water reservoir lower than itself, so that it could never be affected by back-water, and so large that there would never be a demand for sudden changes in the rate of filtration.

This procedure has given excellent results in the German works; but it leads oftentimes to expensive construction. It involves, in the first place, a much greater loss of head in passing through the works, because the pure-water reservoir must be lower than the filters, and the cost of the pure-water reservoir is increased greatly because of its large size. The regulation of the filters is put upon the attendants entirely, or upon automatic devices, and regulation by what is known as "responding to the pumps" is eliminated.

More recently the German authorities have shown less disposition to insist rigidly upon the principles advanced in 1894. In a compilation of the results of several years' experience with German water filters, Dr. Pannwiz * makes a statement of particular interest, of which a free translation is as follows: —

"Most of the German works have sufficient pure-water reservoir capacity to balance the normal fluctuations in consumption, so that the rate of filtration is at least independent of the hourly fluctuations in consumption. Of especial importance is the superficial area of the pure-water reservoir. If it is sufficiently large there is no objection to allowing the water level in it to rise to that of the water upon the filters. With very low rates of consumption during the night the filters may work slowly and even stop, without damage to the sedi-

* *Arbeiten aus dem Kaiserlichen Gesundheitsampte*, Vol. XIV, p. 260.

ment layers when the stopping and starting take place slowly and regularly, because of the ample reservoir area.

"The very considerable fluctuations from day to day, especially those arising from unusual and unforeseen occurrences, are not provided for entirely by even very large and well-arranged reservoirs. To provide for these without causing shock, the rate of filtration must be changed carefully and gradually, and the first essential to success is a good regulation apparatus."

"Responding to the pumps" has a great deal to recommend it. It allows the pure-water reservoir to be put at the highest possible level, it reduces to a minimum the loss of head in the plant, and yet provides automatically, and without the slightest trouble on the part of the attendants, for the delivery of the required quantity of water by the filters at all times. If the filters are connected directly to the pumps there is a tendency for the pulsations of the pumps to disturb their operation, even if the pumps are far removed; and this exists where filters are connected directly to the pumps, and a pure-water reservoir is attached to them indirectly. By taking all the water through the pure-water reservoir and having no connection except through it, this condition is absolutely avoided, and the pull on the filters is at all times perfectly steady.

Much has been said as to the effect of variation in the rate of filtration upon the efficiency of filters. Experiments have been made at Lawrence and elsewhere which have shown that, as long as the maximum rate does not exceed a proper one, and under reasonable regulations, and with the filter in all respects in good order, no marked decrease in efficiency results from moderate fluctuations in rate. There is probably a greater decrease of efficiency by stopping the filter altogether, especially if it is done suddenly, than by simply reducing the rate. The former sometimes results in loosening air bubbles in the sand, which rise to the surface and cause disturbances, but this is not often caused by simple change in rate.

On the whole, there is little evidence to show that, within reasonable limits, fluctuations in rate are objectionable, or should be excluded entirely, especially in such cases as at Albany, where arrangements to prevent them would have resulted in very greatly increased first cost. The inferior results sometimes obtained with the system of "responding to the pumps" as it existed in earlier works, and still exists in many important places, undoubtedly arises from the fact that there is no means of knowing and controlling the simultaneous rate of filtration in different filters, and that one filter

may be filtering two or three times as fast as another, with nothing to indicate it.

This contingency is fully provided for in the Albany plant. The orifices are of such size that even with a filter just scraped and put in service, with the minimum loss of head, with the outlet gate wide open, and with the water level in the pure-water reservoir clear down, — that is, with the most unfavorable conditions which could possibly exist, the rate of filtration cannot exceed 5 000 000 or 6 000 000 gallons per acre daily, or double the nominal rate. This rate, while much too high for a filter which has just been cleaned, is not nearly as high as was possible, and in fact actually occurred in the old Stralau filters at Berlin, and in many English works; and, further, such a condition could only occur through the gross negligence of the attendants, because the rate of filtration is indicated clearly at all times by the gages. These regulating devices have been specially designed to show the rate with unmistakable clearness, so that no attendant, however stupid, can make an error by an incorrect computation from the gage heights. It is believed that the advantage of clearness by this procedure is much more important than any increased accuracy which might be secured by refinements in the method of computation, which should take into account variations in the value of the coefficient of discharge, but which would render direct readings impossible.

In designing the Albany plant the object has been to combine the best features of German regulation with the economical and convenient features of the older English system, and filters are allowed to respond to the pumps within certain limits, while guarding against the dangers ordinarily incident thereto.

RESULTS OF OPERATION.

The filters were designed to remove from the water the bacteria which cause disease. They have already reached a bacterial efficiency of over 99%, and it is expected that their use will result in a great reduction in the death rate from water-borne diseases in the city. They also remove a part of the color and all of the suspended matters and turbidity, so that the water is satisfactory in its physical properties.

The filters have reached, with perfect ease, their rated capacity, and on several occasions have been operated to deliver one third

more than this amount; that is to say, at a rate of 4 000 000 gallons per acre daily. They are operated by Mr. George I. Bailey, Superintendent of the Albany Water Works.

COST OF CONSTRUCTION.

The cost of the filtration plant complete is shown by Table No. 3. As some of the accounts are not yet closed, a few of the items, designated by stars (*) are estimated, and are subject to slight change with the closing of all the accounts.

The filters, sedimentation basin, and pure-water reservoir are connected in such a way as to make an exact separation of their costs impossible; but, approximately, the sedimentation basin cost $60 000, the pure-water reservoir $9 000, and the filters $255 000. The sedimentation basin thus cost $4 100 per million gallons capacity; and the filters complete, including all piping, cost $45 600 per acre of net filtering area, exclusive of land and engineering.

TABLE No. 3. — Approximate Cost of Filtration Plant Complete.

Land		$8 290.00
Pumping Station:		
Pumping machinery, boilers, etc.	$22 000.00	
Intake	3 800.00	
Pump well, gates, screens, and foundations	6 285.00	
Pumping station building	12 167.00	
Chimney	1 540.00	
Venturi meter	1 560.00	
Extra work and minor items	2 393.00*	
		49 745.00*
Filters, Sedimentation Basin, and Pure-water Reservoir: —		
Preliminary draining	$1 956.71	
70 672 cu. yds. excavation, at (average) $0.3079+	21 761.64	
16 040 cu. yds. rolled clay and gravel embankment, at $0.52	8 340.80	
22 851 cu. yds. silt and loam filling, at $0.15	3 427.65	
23 439 cu. yds. general filling rolled, at $0.18	4 219.02	
12 550 cu. yds. puddle, at $0.715	8 973.25	
1 775 cu. yds. gravel for lining, at $0.85	1 508.75	
2 257 sq. yds. split stone lining, at $0.82	1 850.74	
11 737 cu. yds. concrete in floors, at $2.31	27 112.47	
Carried forward	$79 151.03	58 035.00*

Brought forward	$79 151.03	$58 035 00*
7 792 cu. yds. concrete in vaulting, at $3.85	29 999.20	
3 147 cu. yds. all other concrete, at $2.13	6 703.11	
4 382 cu. yds. brick work, at $8.125	35 603.75	
31 715 barrels Portland cement, at $1.935	61 368.53	
7 281 cu. yds. filter gravel, at $1.05	7 645.05	
36 488 cu. yds. filter sand, at $1.00	36 488.00	
Cast-iron pipes and specials, placed, including placing gates	21 841.25	
Gates and valves	6 714.23	
Vitrified pipe. complete	7 153.32	
672 filter manhole covers, at $4.40	2 956.80	
8 sand-run fixtures, at $407.50	3 260.00	
8 regulator houses, at $862.24	6 897.92	
1 office and laboratory	4 881.00	
Vitrified brick paving	2 158.00	
Iron fence about court	1 704.00	
Extra work and all minor items	9 692.01	
		324 217.20
Conduit and Connections with Quackenbush Street Pumping Station: —		
7 913 ft. 48-in. steel pipe, at $4.50	$35 608.50	
24 218 cu. yds. excavation, at (average) $0.855+	20 715.60	
3 144 cu. yds. concrete, at $5.00	15 720.00	
Gates and connections with pumping station	3 680.00	
Sewer and railroad crossings, sheeting, and all other items	10 914.12	
		86 638.22
Engineering, inspection, printing, etc.		31 000.00*
Total approximate cost of work		$499 890.42*

The preliminary estimate of cost submitted to the Board, February 8, 1897, amounted to $478 000. The work will actually cost, in round numbers, $22 000, or 4.6% more than the preliminary estimate. The preliminary estimate, and the actual costs by more important divisions, are as follows: —

	Preliminary estimate, Feb. 8, 1897.	Approximate actual cost.
Land	$10 000	$8 290
Pumping station and intake	34 000	49 745
Filters and sedimentation basin. with piping	327 000	324 217
Pure-water conduit and connection with Quackenbush Street pumping station	64 000	86 638
Engineering and contingencies	43 000	31 000
Total	$478 000	$499 890

The excess in the cost is in the pumping station and conduit line. The cost of the conduit line was increased by surrounding it with concrete, which was not included in the preliminary estimate, and also by certain changes in the location required by the canal authorities. The pumping station also was made more elaborate and expensive than was contemplated in the preliminary estimate. Otherwise the work was executed substantially as first planned.

ACKNOWLEDGMENT.

The general plan and location of the plant were first conceived by the Superintendent of Water Works, Mr. George I. Bailey, and the successful execution is largely due to his efforts. The members of the Water Board, and especially the Construction Committee, have followed the work in detail closely and personally, and their interest and support have been essential factors in the results accomplished. In the designs and specifications for the pure-water conduit the author is greatly indebted to Mr. Emil Kuichling, and also for most valuable suggestions relative to the performance of this part of the work. To Mr. William Wheeler, of Boston, the author is indebted for advice upon the vaulting and cross-sections of the walls, and these matters were submitted to him before the plans were put in final shape. All the architectural designs have been supplied by Mr. A. W. Fuller, of Albany. Mr. W. B. Fuller, as Resident Engineer, has been in direct charge of the work, and its success is largely due to his interest in it and the close attention which he and the assistant engineers have given it.

DISCUSSION.*

BY MR. GEORGE I. BAILEY, SUPERINTENDENT, ALBANY WATER WORKS.

OPERATION.

Two filters were put in service July 27, 1899. Four more were started July 28. All of these ran until August 9, and three of them continued until August 12. They were started with the hope of continuing, but the conditions were unfavorable in that the water was pumped direct to the filters, as the sedimentation basin was not ready for use; the court between the filters, in which scraped sand

* Abstracted by the editor from a discussion in *Proceedings American Society of Civil Engineers*, February, 1900.

was to be deposited, washed and stored, was neither leveled nor paved; and the water in the river was roiled and disturbed by the contractors' operations, and particularly with the wash-water from the sand being prepared for the remaining two filters. The run of the filters was, therefore, stopped and not again commenced until September 5, since which time their operation has been continuous.

COST OF OPERATION.

The work was organized as follows: —

Filter operation:	10 laborers,	at	$1.50 per day.
	1 foreman	,,	2.75 ,,
	1 watchman	,,	1.50 ,,
	1 chemist	,,	1 000.00 per year.
Pumping Station:	3 engineers	,,	75.00 per month.
	3 firemen	,,	60.00 ,,

The working day is eight hours for laborers, engineers, and firemen, and overtime is paid for at the rates named. Occasionally, extra help has been hired, and paid for at these rates.

The gross cost of operation, including pay roll, tools which are still in use, repairs, supplies of all kinds, wash-water, etc., for the period from September 5 to December 25, inclusive, 118 days, was $6 164.94. In this time 1 470 000 000 gallons were filtered, making an average of $4.19 per million gallons delivered from the filters.

The master mechanic of the works gives the following statement from his records, as the daily cost at the pumping station: —

3 engineers	at	$2.48	$7.44
3 firemen	,,	1.98	5.94
3 tons coal	,,	2.72	8.16
1 laborer	,,	1.50	1.50
9 gallons engine oil	,,	0.09	0.81
2 gallons cylinder oil	,,	0.11	0.22
5 gallons kerosene oil	,,	0.10	0.50
5 lbs. waste	,,	0.07	0.35
Steam packing, sheet rubber, soap, soda, mops, cloths, etc.			6.58
Total			$31.50

This makes the average cost of pumping $2.52 per million gallons received from the filters, and leaves $1.67 as the cost of operating the filters, including laboratory work. The cost of scraping, wheel-

ing out, washing and replacing sand for the actual number of hours, and exclusive of superintendence, laboratory work, lost time, tools, etc., is $1.19 per million gallons treated.

BACTERIA.

Table No. 4 shows the weekly averages of the bacterial removal.

TABLE No. 4.

1899. Week ending	Bacteria Per Cubic Centimeter.		Percentage of removal.
	Unfiltered.	Filtered.	
September 9	11 545	608	94.8
16	14 083	306	97.8
23	17 480	273	98.5
30	22 600	259	98.8
October 7	18 766	250	98.7
14	11 783	178	98.5
21	9 933	85	99.1
28	4 733	84	98.4
November 4	6 091	56	99.1
11	5 141	46	99.1
18	7 950	69	99.1
25	11 090	79	99.3
December 2	19 240	109	99.4
9	20 016	198	99.1
16	57 700	142	99.7
23	66 000	327	99.5
30	48 940	215	99.6

CLEANING THE FILTERS.

The filters have been cleaned 26 times in all, up to December 25, or a little more than three times each. The total amount of sand treated, as measured when replaced, was 850 cubic yards. From the books of the foreman, the following records are taken : —

Scraping. — 88 452 sq. yds. = 18.3 acres ; time, 1 227 hours = 67 hours per acre.

Wheeling out Scraped Sand. — 23 180 barrows, 2 235 hours, 27.3 barrows per cubic yard = 0.38 cu. yd. per hour. The average length of wheel, going and coming, was 600 feet = 1.18 miles per man per hour.

Washing. — 18 262 barrows, 2 068 hours, 21.5 barrows per cubic yard = 0.41 cu. yd. per hour.

The volume of water for washing the sand varied from 12 to 14 times the volume of sand washed. In the cost of operation the volume has been estimated at 15 times that of the sand, at a cost of $0.04 per thousand gallons.

Refilling. — 18 550 barrows, 1 630 hours, 21.8 barrows per cubic yard = 0.52 cu. yd. per hour. This work was chiefly done by extra labor.

The average depth of scraping was about $\frac{3}{8}$ inch, computed from the total quantity of sand replaced and the area scraped.

During the periods covered by these scrapings, the filters yielded 1 212 000 000 gallons, an average of 66 600 000 gallons per acre between scrapings. This includes the first run of the filters, when the unnaturally turbid water already mentioned was pumped directly on the beds.

COLOR.

The average color of the Hudson River water corresponds to 0.50 to 0.60 on the platinum scale, and about 40% of this color is removed from the water by the filters.

TURBIDITY.

In periods of freshet the water is very turbid. The highest turbidity reached since the operation of the filter was in December, when the raw water showed 0.60. The effluent then contained 0.008. Generally the raw water runs about 0.035, all of which is removed. The platinum-wire standard is used.

TYPHOID FEVER.

The reason for building the filters was the sewage pollution of the Hudson River, and the large death rate from typhoid fever. The average number of deaths from this cause for the nine years ending with 1898 was 85 per annum. During the four months in which the filters have been in operation seven deaths from this cause have been reported. For the corresponding months of the nine years ending with 1898 the average number has been 24. The deaths from this cause have thus been reduced in the ratio of 24 to 7, and one of these seven was in a family which did not use city water.

MECHANICAL FILTRATION.

BY EDMUND B. WESTON, C. E., PROVIDENCE, R. I.

[*Read January 10, 1900.*]

It is my intention to say a few words this afternoon in regard to the purification of city and town water supplies by the use of sulphate of alumina in connection with the subsidence gravity system of mechanical filtration.

There are other systems of mechanical filtration, which I presume are well known to you; but as the subject is a very exhaustive one, and as my experience in regard to mechanical filtration has been mostly in connection with this system, it is my intention to confine myself to it.

To aid in my explanations, I will show you a number of views illustrating the details of the subsidence gravity filter and its necessary auxiliaries, as well as views of several filter plants which were designed under my direction.

Before going into details, I will first briefly outline the

PROCESS OF FILTRATION.

To the water to be purified is first added the desired quantity of sulphate of alumina in the form of a weak solution. The water then passes slowly through the subsidence basin, where coagulation takes place, or, in other words, the sulphate of alumina is decomposed and a flocculent gelatinous precipitate of aluminum hydrate is formed. This flocculent precipitate surrounds, entangles, and aggregates the suspended matter, bacteria and inorganic substances, and slowly carries them down through the water, and, as a result, the greater part of them are finally deposited upon the bottom of the subsidence basin. Generally speaking, it may be said that the action of the aluminum hydrate is much the same as the action of the white of an egg in clearing turbid coffee. From the subsidence basin the partially clarified water flows to, upon, and through the filter bed, which acts as a strainer and removes the remaining coagulated particles, including bacteria. A further action of the aluminum hydrate is to unite

with the soluble coloring matter in the water, thereby rendering the effluent nearly colorless.

In a very few minutes after a filter is put in operation a thin gelatinous layer is formed upon the top of the filter bed, which adds materially to the thoroughness of the process of filtration.

When the filter bed has become clogged, it is thoroughly cleansed by forcing up through it a reverse flow of water under pressure, a mechanical rake or agitator being operated at the same time, which is of great advantage for the efficient cleansing of the filter bed. When the subsidence basin is washed out, it is done by allowing the wash water, after it has passed up through the filter bed, to overflow through a central standpipe down into the subsidence basin. By a special appliance, the water as it enters the subsidence basin from the standpipe is swashed about the bottom and sides of the basin.

The principal parts of a subsidence gravity filter and the appliances required in connection with the use of sulphate of alumina may be roughly described as: —

1. The apparatus used for the preparation and addition of the sulphate of alumina solution.

2. The subsidence basin in which coagulation takes place, and in which the water is partially clarified by subsidence.

3. The filter bed through which the water finally passes.

FILTER.

Fig. 1 shows a section of a standard 12 foot subsidence gravity filter. Mr. O. H. Jewell, of Chicago, Ill., is the designer of this type of filter. The outside diameter is 13.5 feet; the diameter of the filter bed is 12 feet, and the total height of the filter 16 feet. Its capacity is from 259 000 to 332 000 gallons per 24 hours, depending upon the character of the water. The rates of filtration corresponding are from 100 000 000 to 128 000 000 gallons per acre per 24 hours.

The tanks of the filter are shown to be constructed of wood. They are generally of well-seasoned selected cypress or cedar, dressed on both sides to $2\frac{3}{4}$ inches thick; but they are also built of iron or steel, if desired. Both the main and inner tanks, when of wood, are bound with extra heavy wrought-iron hoops.

The timbers supporting the inner or filter-bed tank are of hard wood, and very large and strong, so that no great weight or strain is

carried on the staves. The upright timbers rest upon a heavy secondary floor, laid upon the bottom of the main tank, for the purpose of distributing the weight.

Diametrically across the floor of the filter-bed tank are laid heavy cast-iron manifold sections, which are held together with machine bolts. The strainer pipes, or branch pipes, which are screwed into these manifolds at equal distances along the same, are of brass or iron, and extend to the side of the filter-bed tank, being cut in various lengths to fit the circle. These pipes are capped on the ends by

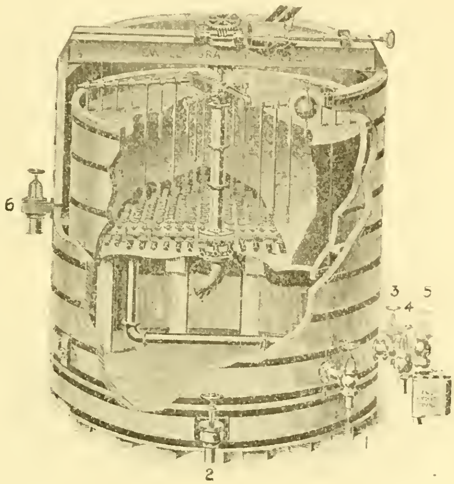


FIG. 1.—SECTION OF SUBSIDENCE GRAVITY FILTER.

reducing elbows. The collecting and wash strainers are evenly spaced along these pipes, and securely screwed into them.

The central manifold is provided with a flange opening to which is bolted a central standpipe that extends several inches above the top of the filter bed.

The stirring apparatus consists essentially of a heavy cross arm, which swings on a vertical shaft extending from the cross beams on top of the filter to the deflecting elbow in the subsidence tank. Into this cross arm are keyed four heavy horizontal shafts, which carry the swinging rakes or bars. These bars are secured in swivel collars, having quadrant lugs which engage the swivel collars when the agitator bars are vertical in the filter bed. These rakes or bars are

arranged to traverse the bed about every three inches, thereby reaching all its parts.

The agitating device shown upon this filter in the cut is a worm and worm wheel, which are combined in one heavy cast-iron casing. The casing provides for a well of oil in which the worm and wheel dip, so that both are continuously running in oil when in operation. The worm shaft is fitted with an end support secured to the cross beams on top of the filter, and is provided with either duplex friction clutches operated with one lever, or tight and loose pulleys with shifter rods if preferred. Other agitating devices are sometimes used that do away with the worm gears, consisting of bevel and spur gears and pinions. These latter devices are always used upon filters having a diameter greater than 15 feet, and I generally recommend their use upon all filters having a filter bed greater than 10 feet in diameter.

The "down draft" or delivery pipe for carrying off the filtered water extends from the bottom of one of the manifold sections to near the floor of the subsidence basin, and thence out from the basin to a "cross" outside of the filter.

The inlet pipe enters on the side of the subsidence basin somewhat above the bottom, and is provided with a balanced float valve connected with a float on top of the filter, to regulate the incoming water and keep the filter uniformly full of water.

There is a manhole for entering the subsidence basin.

The filtered water delivery pipe is fitted with an automatic controller for maintaining a uniform rate of filtration, and through which the filtered water is finally discharged. This device needs no attention whatever and may be adjusted to any rate of delivery desired.

A different controller, of later design than the one shown connected to the filter, is now used, and will be described in detail in due course.

An opening is provided in the "cross" on the outside of the filter to which a steam connection can readily be made for the sterilization of the filter bed, whenever this becomes necessary.

The filtering material is generally from 3 to 4 feet in depth and is composed of crushed quartz or a specially mined sand. The wash and collecting strainers are made entirely of brass, with bronzed screens and deflecting plates, and are all securely copper riveted. There are 444 of these strainers in a 12 foot filter. Each screen has about 900 holes of about $\frac{3}{100}$ of an inch in diameter.

Filters of this design, for the purification of city and town water supplies, have filter beds ranging from 10 to 24 feet in diameter. The capacity for a filter having a bed 10 feet in diameter would be from about 179 000 to about 229 000 gallons per 24 hours, and for a filter having a bed 24 feet in diameter from about 1 000 000 to about 1 319 000 gallons per 24 hours.

VALVES AND CONNECTIONS.

The raw water main for supplying the filters is connected to inlet valve No. 1 (Fig. 1). Valves Nos. 2, 3, and 6 are for washing and cleaning, and are connected to a waste pipe or sewer. Valve No. 4 is connected with a pipe which conveys water for washing the filter bed and subsidence basin. Valve No. 5 is directly connected to the controller, which discharges the filtered water into a flume or clear water basin or reservoir. Valves Nos. 2 and 6 may be placed at any point around the filter, and, in most instances, are placed so as to both discharge into the same waste pipe or sewer. Valve No. 1 may also be located at any desired point around the filter.

WASHING.

To wash the filter, all valves having been previously closed, open washout valve No. 6 wide. This allows all water above the inner tank and in the annular trough to drain out. Then open valve No. 4 slowly until sufficient water is flowing up through the filter bed to render it semi-fluid, thereby allowing the agitator to move easily. When the wash water has begun to flow freely over into the annular trough, the stirring apparatus may be started on the forward motion. The rakes or bars then penetrate the semi-fluid filter bed, and thoroughly agitate and scour the same, the wash water sweeping all the sedimentary matter over the edge of the inner tank into the annular trough, from which it is discharged through washout valve No. 6 to the waste pipe or sewer. From five to ten minutes are usually allowed and found sufficient to completely cleanse all of the filtering material. When the filter bed is sufficiently clean, first reverse the motion of the stirring apparatus while the current of wash water is still on, so that the rakes or bars will come out of the filter bed and rest upon its surface; and while they are running backward slowly close wash valve No. 4; then stop the agitator and close washout valve No. 6.

In washing a filter a pump is generally required for forcing the

water up through the filter bed. The pump can be driven by steam or water power. Steam or water power is also required for driving the agitator.

REWASHING, OR FILTERING TO WASTE.

After the filter has been washed open inlet valve No. 1 slowly, and when the filter is nearly full of water open rewash valve No. 3 one or two turns; when the effluent comes clear and is satisfactory in appearance, close rewash valve No. 3 entirely; allow inlet valve No. 1 to remain entirely open. The object of rewashing or filtering to waste immediately after washing the filter is to displace any turbid or impure water remaining in the filter bed. Filtered water is preferably used for washing. It is obvious, therefore, that this operation is only imperative when the raw water is used for washing, and also that only a minute or two is required to completely displace the turbid waste with pure filtered water. When a filter bed is washed with filtered water rewashing is seldom found necessary.

FILTERING.

After rewashing, open valve No. 5 slowly.

In this operation the raw water, which has been previously charged with the sulphate of alumina solution, enters the subsidence basin through inlet valve No. 1. The water is then slowly circulated around this basin by the deflecting flange on the inside directly in front of the inlet pipe. In this way the incoming water is prevented from causing local or short-cut currents. Subsidence takes place very rapidly, and before the water reaches the upper central discharge from the basin into the standpipe, generally all of the heavy matter and most of the finer impurities, including bacteria, which have been coagulated, are precipitated. It is variously estimated that from 50 to 75 per cent., by weight, of the suspended impurities are caught in this basin alone. Tests have actually proven that from 40 to 80 per cent. of the bacteria have been retained in these subsidence basins. The water after subsidence leaves the basi and rises through the central standpipe and overflows upon the filte. bed. A low head of water, generally about 2 feet, is carried upon the filter bed so as to prevent the incoming water from cutting channels or furrows in the bed. The water then proceeds downward through the filter bed, depositing thereon and therein the coagulated

matters, impurities and bacteria, which have resisted subsidence, and thence it is collected evenly and proportionately from all parts of the bed by the strainer system, first entering the numerous strainers themselves, then the parallel branch pipes and manifolds, and finally coming together in one volume in the "down draft" or delivery pipe, which runs directly to the outside of the filter and communicates with the "cross" to which valves Nos. 3, 4, and 5 are attached. From the latter valve it is discharged into the controller, clear and bright.

RATE OF FILTRATION AND TIME ALLOWED FOR SUBSIDENCE.

The rate of filtration, or the velocity of the water when it flows through the filter bed, is generally from about 100 000 000 to 128 000 000 gallons per acre per 24 hours, which corresponds to from 1.59 to 2.04 gallons per square foot of filter-bed surface per minute. At these rates of filtration the time which is allowed for subsidence in a 12 foot filter, or the time that it takes for a quantity of water to flow through the subsidence basin equal to its cubic contents, is from 30 to 40 minutes. In filters of larger diameter, the time is somewhat more.

For water containing large quantities of suspended matter, like some Southern and Western waters, a longer time for subsidence is required than can be had in the filters. This is accomplished by using one or more auxiliary subsidence basins, built independent of the filters proper, of such capacity as the conditions of the case may necessitate.

CLEANING THE SUBSIDENCE BASIN.

This operation is carried on simultaneously with the washing of the filter bed, and the same wash water cleanses both filter bed and subsidence basin. The operation is automatic. In cleansing the basin, valve No. 2, instead of washout valve No. 6, is opened wide and the filter bed washed in the manner previously described. As washout valve No. 6 remains closed, the dirty wash water, instead of overflowing the inner tank and escaping through washout valve No. 6, is compelled to rise above the central standpipe and then overflows down through it into the subsidence basin. At the bottom of the standpipe, the falling water comes in contact with a large open deflecting elbow, which is fastened to the same vertical shaft that

carries the agitator or rakes, and therefore revolves with it, and the water is thrown with considerable violence against the lower sides and bottom of the basin, and is discharged through valve No. 2, carrying with it even the heaviest accumulations of sediment.

STERILIZING.

It has been found advantageous to sterilize a filter bed once in about six months. This is generally done by the use of steam and soda ash. The water in the filter is drained off, with the exception of the water in the filter-bed tank, which is allowed to remain to a depth of about 8 inches above the top of the filter bed. All of the regular valves are then closed, a few pounds of soda ash scattered into the water, and steam let into the filter-bed tank from the sterilizing pipe, through the same interior pipes and strainers where the wash water is let in and the filtered water flows out. The filter bed is then boiled from 30 to 60 minutes. At the completion of the boiling the water is drawn off, and the filter bed is washed in the usual way several times. When the filter is again put in service, the filtered water is allowed to waste for a time through the rewash pipe.

The advantage of being able to sterilize a filter bed is considered to be of great importance.

APPLICATION OF THE SULPHATE OF ALUMINA SOLUTION.

The sulphate of alumina is first dissolved in a mixing tank. Two or more tanks are always used, so that while one is supplying the solution, the operation of mixing can be carried on in another tank. Gages are attached to the mixing tanks so that the quantities of sulphate of alumina solution flowing from them can be accurately measured.

The solution may be fed into the raw water by gravity or by the use of a small auxiliary pump, operated automatically either by steam or mechanical connection to the main pump which supplies the raw water to be filtered, or the pump may be driven by a propeller placed in the supply pipe.

Fig. 2 shows the method of application by the Warren chemical pump. This is of rubber, and has six hollow arms bending at the hub and passing along the pump axis to a deflecting cup, where

the liquid is thrown down into a funnel, from whence it flows through a small pipe into the main pipe that supplies the raw water to be filtered. This pump is driven by a propeller, placed in the main supply pipe. The speed of the wheel, and therefore of the pump, corresponds with the velocity of the incoming water, so that a given standard solution is fed in exact proportion to the amount of raw water being treated.

The pump revolves in a small tank containing the sulphate of alumina solution, and takes up the proper quantity of the solution and passes it into the hub, and thence to the deflecting cup.

By lowering the level of the solution in the pump tank, or by inserting plugs or reducing orifices in the arms of the pump, the

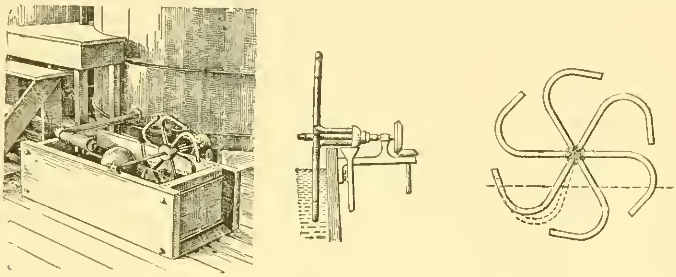


Fig. 2.—Warren Chemical Pump.

amount of solution used per gallon of raw water may be varied without changing the strength of the solution.

The sulphate of alumina solution flows by gravity to the pump tank, from the mixing tank or tanks in which it is prepared, through a small pipe. A rubber valve connected to this pipe and a rubber float in the pump tank regulate the flow of the solution into the pump tank and keep it at the desired level.

Plate I, Fig. 1, represents a chemical pump which may be used for feeding the sulphate of alumina solution. It is a single acting duplex pump, and the parts which are exposed to the solution are made of or are covered with rubber. This pump is driven by a belt leading from the main pumping machinery which supplies the raw water to be filtered. The length of stroke is easily adjusted, so that the solution can be applied at different rates if desired.

Fig. 3 shows a method by which the sulphate of alumina solution can be fed to the raw water by gravity. The solution flows by gravity through a small pipe from the mixing tank or tanks to the grav-

ity tank. A rubber valve connected to this pipe and a rubber float in the gravity tank regulate the flow of the solution into the gravity tank and keep the level of the solution in the same at a constant elevation. The solution is discharged into the raw water by gravity from the gravity tank through a pipe which terminates in a small valve, which is arranged so that an orifice of proper diameter can be

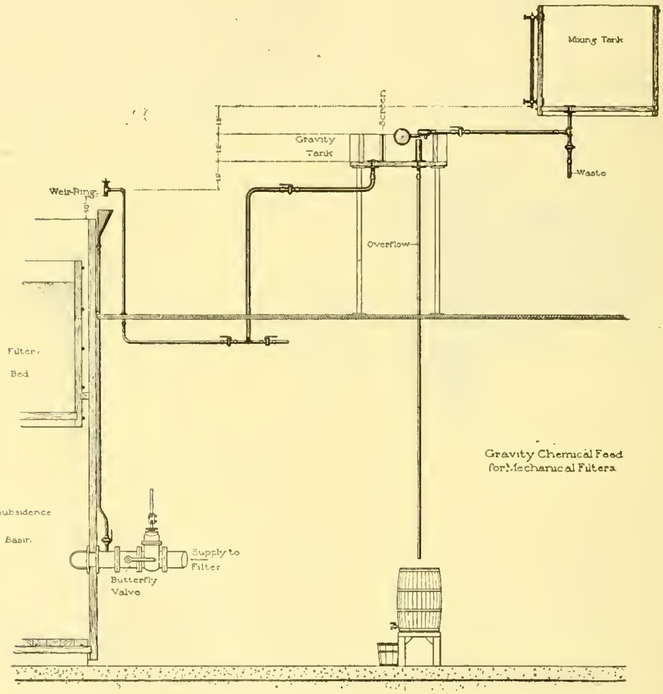


FIG. 3.

attached to it, thereby regulating the discharge to the correct amount. The discharge is into a funnel at the side of the filter, and thence the solution passes down through a small pipe into the supply pipe through which the raw water to be filtered flows. When more than one filter is supplied by this system of gravity feed, a main pipe sufficiently large so that there will not be any appreciable friction when the solution flows through it is run from the gravity tank past the filters, and a branch is laid from this main pipe to each filter.

AUTOMATIC CONTROLLER.

An accurate automatic controller for measuring the flow through the filter fled and keeping it perfectly constant during the process of filtration is of the utmost importance. The two principal reasons for the necessity of an accurate controller are: first, the exact quantity of water passing through the filter bed being known, the cor-

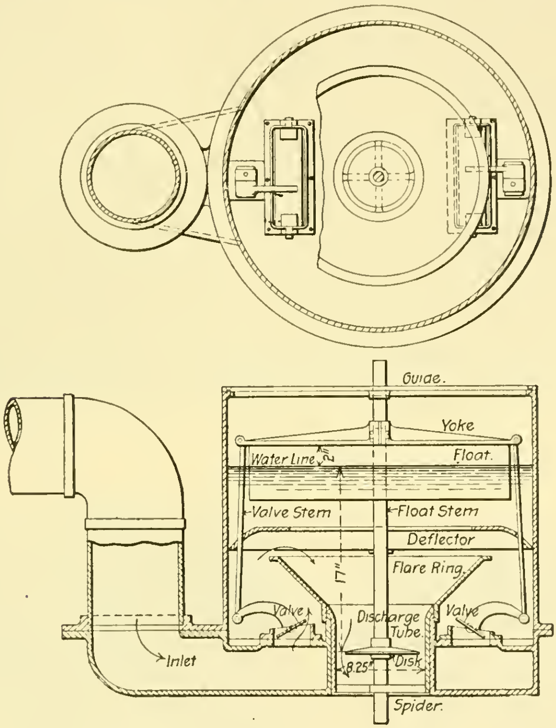


FIG. 4. — AUTOMATIC CONTROLLER.

rect quantity of sulphate of alumina solution can be accurately and uniformly applied to the raw water by gravity or other means; and second, by keeping the flow of water through the filter bed perfectly constant, scouring action in the bed is avoided.

Fig. 4, reproduced from a cut in the *Engineering Record*, shows such a controller.

The controller is connected (outside of the filter) to the "down draft," or delivery pipe, from which the filtered water passes through

butterfly valves in the lower part of the controller. It contains a float mounted on a hollow float-stem operating in guides at the top and bottom. Beneath the float is a deflector, designed to quiet the incoming water and reduce any currents, thereby giving a smooth entrance to the discharge tube, and being aided in this respect by the flaring ring on the discharge tube. Mounted also on the float-stem, so as to be maintained at a constant depth, is a disc which is turned with a thin edge and sharp corners, and of such a diameter as will give the annular orifice between the disc and the walls of the discharge tube a predetermined area proportional to the desired rate of discharge.

The inlet butterfly valves in the lower part of the controller are operated by levers connected to the float. The flow of water from the filter is regulated as follows: With a given head or pressure on the surface of the filter bed and free discharge from the filter, the rate of discharge will vary with the condition of the filter bed. If for a given level of water in the controller the pressure in the inlet pipe be such that more water will pass through the inlet butterfly valves than can be discharged through the annular orifice, the level of the water in the controller will rise, and with it the float, which will tend to close the inlet butterfly valves and throttle the flow until equilibrium is established between the supply to and the discharge from the controller. If, on the other hand, the pressure on the inlet pipe be reduced, and consequently the flow through the valves, the water level falls, and the float falling with it increases the opening of the valves and thus restores the equilibrium.

Should the head on the inlet pipe be reduced below that determined as the minimum limit, the water level in the controller will fall below the minimum limit, the float will be submerged less, and consequently the head on the annular orifice and discharge tube will be diminished below the minimum desired. This will indicate a needed washing of the filter bed, which is generally manifested to the operator by an indicating water gage, actuated by a float in a small vertical pipe that is connected to the inlet pipe of the controller. The rated capacity of discharge may be adjusted by altering the depth of submergence of the disc, or by changing the area of the annular orifice by substituting a disc of different size. Air is admitted below the disc through the hollow float-stem, which has vents below the disc.

Tests have been made with this design of controller under heads

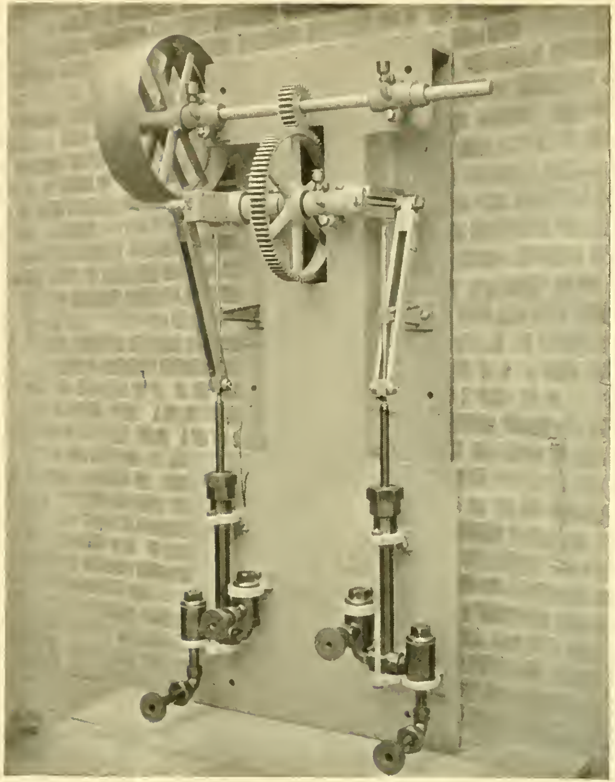


Fig. 1.—Chemical Pump.

Fig. 2.—Operating Floor, Norfolk, Va.

Fig. 3.—Interior of a Subsidence Basin.

ranging from 0.33 to 18 feet above the level of the water within it. These tests have shown no measurable variation in the discharge.

EAST PROVIDENCE, R. I., FILTER PLANT.

Fig. 5* shows a filter plant at East Providence, R. I., which went into service in March, 1899. The cut shows a longitudinal section through the filter building, showing the filter and auxiliaries

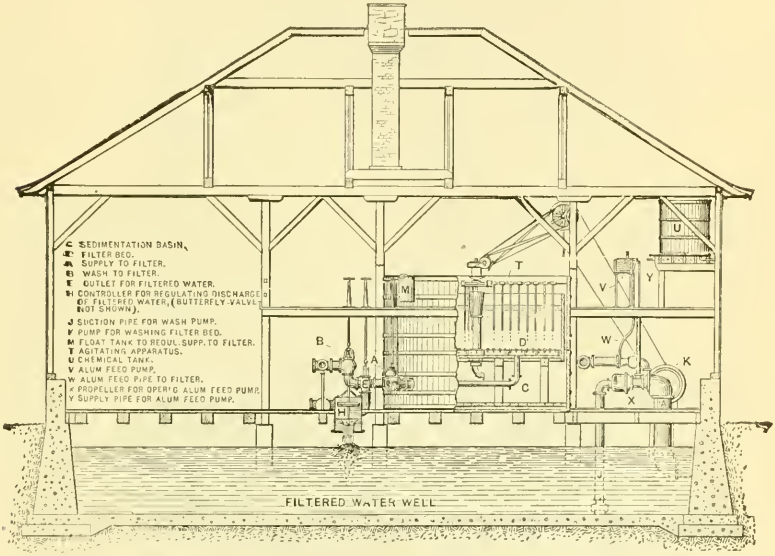


FIG. 5.—EAST PROVIDENCE FILTER PLANT.

and pure water well, including operating floor, chemical mixing tanks, Warren chemical feed pump, wash pump, power transmission, controller, etc. There is one filter. The diameter of the filter bed, which consists of crushed quartz, is 15 feet, and its available capacity is 500 000 gallons per 24 hours, the rate of filtration being about 125 000 000 gallons per acre per 24 hours. The raw water is supplied to the filter by gravity. The filtered water is discharged into a pure water well under the building.

On account of being able to supply the raw water by gravity, the filter is not of the standard height, but is only 12 feet high instead

* Electrotype from cut in *Proc. Am. Soc. C. E.*

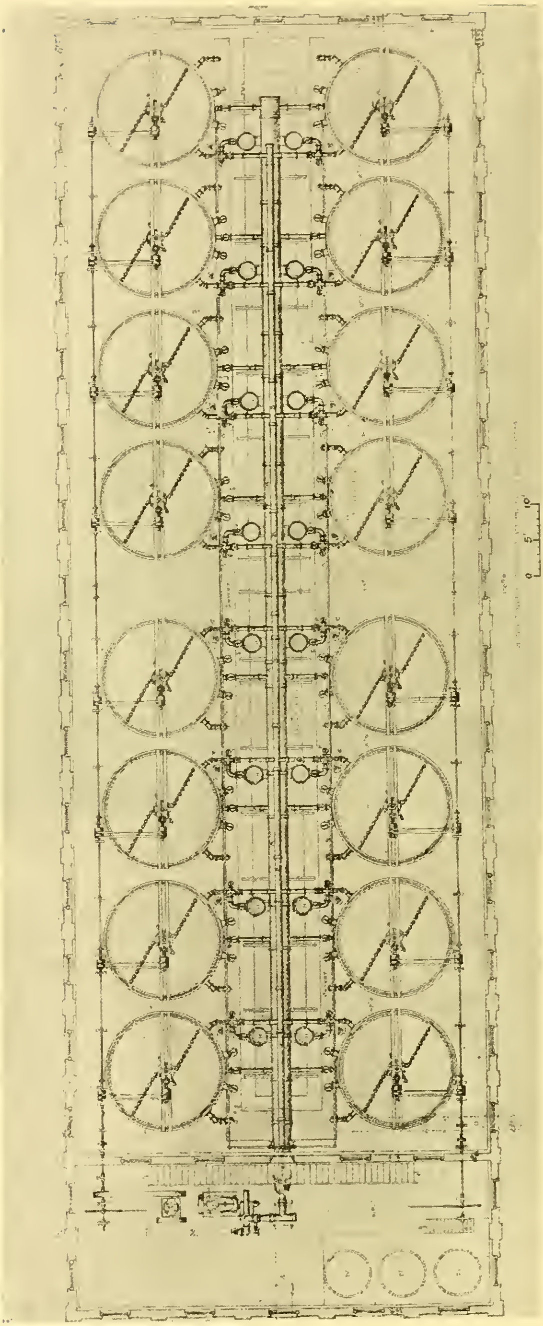


FIG. 6. — PLAN OF FILTER BUILDING, NORFOLK, VA.

of 16 feet, which reduces the time allowed for subsidence in the filter to about 17 minutes.

The power for driving the agitator and wash pump is transmitted by a rope and shafting from a turbine wheel in the adjacent pumping station.

The building is arranged for three additional filters when the requirements of the service demand them.

NORFOLK, VA., FILTERS.

A filter plant at Norfolk, Va., having an available total capacity of 8 000 000 gallons per 24 hours, went into service in August, 1899. This plant is shown in Figs. 6 and 7.

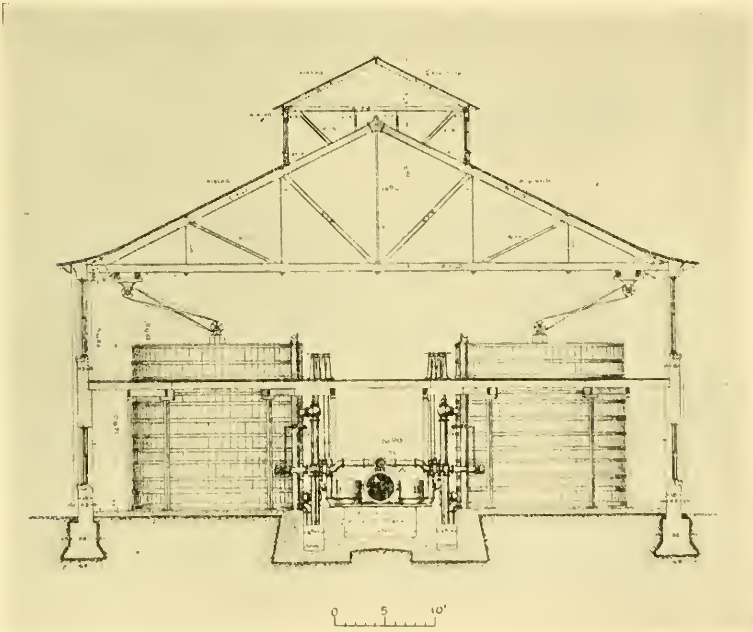


FIG. 7.—SECTION THROUGH FILTER BUILDING, NORFOLK, VA.

The number of filters is sixteen, each of which has a filter bed 15 feet in diameter and of an available capacity of 500 000 gallons per

24 hours. The rate of filtration per acre per 24 hours is about 127 000 000 gallons. The raw water is supplied to the filters by pumping. The filtered water is discharged into a flume, from whence it flows to the pure water reservoir outside of the building.

On account of the peculiar character of the raw water at Norfolk, a longer time for subsidence is required than can be obtained in the filters. This is obtained by using as a subsidence basin a large basin which was formerly used as a reservoir, in which a subsidence of 11 hours or more can be had in addition to the 40 minutes allowed in the filters themselves.

The sulphate of alumina solution is fed from the filter building by gravity, through a small pipe, to the raw water as it flows into a weir chamber at the entrance of the large subsidence basin.

The steam for power is furnished from an adjacent boiler house, which is connected with the main pumping station.

Plate I, Fig. 2, is a view of the operating floor of the filter plant at Norfolk, Va.

Figs. 6 and 7 show an interior plan of the filter building at Norfolk, Va., and a transverse section through the filter building.

ROME, GA., FILTER PLANT.

A filter plant having an available total capacity of 1 500 000 gallons per 24 hours is now being constructed at Rome, Ga. The number of filters is three. Each filter bed is 15 feet in diameter, and the available capacity of each filter is 500 000 gallons per 24 hours, the rate of filtration per acre per 24 hours being about 127 000 000 gallons.

The building is arranged for two additional filters, when required.

A steam boiler is located in the building to furnish the power to operate the filter plant.

The raw water will be supplied to the filters by gravity, and the filtered water will be discharged into a well, from whence it will flow to a pure water reservoir outside of the building.

ARTIFICIAL SUBSIDENCE.

The relatively quick subsidence which takes place in a subsidence basin of a subsidence gravity filter is of so much importance that I will devote a short time to especially describing the process.

The water, as it enters the subsidence basin, as has previously been mentioned, is given a circular motion around the basin by the deflecting flange in which the supply pipe terminates. The movement of rotation is more or less coincident with the surface of a cone whose base is the bottom of the basin and whose apex is the central entrance to the standpipe through which the water flows from the basin to the filter bed. The upright timbers which support the filter-bed tank and the pipes in the interior of the basin all tend to produce counter currents and eddies.

The rotary movement and counter currents and eddies bring about a much quicker subsidence than would be the case in a stationary tank or in a straight unobstructed current of water, as they cause the coagulated particles to meet with and overtake each other, and they are consequently thrown into juxtaposition, thereby forming much larger masses of greater specific gravity.

The next five views are intended to illustrate the practice and theory of the method of subsidence which I have just mentioned.

Plate I, Fig. 3, is from a flash light photograph that was taken of the interior of a 12 foot filter subsidence basin, which is one of a plant of eighteen, in service at Elmira, N. Y.

The upright graduated sticks were inserted in the deposit at the bottom of the basin for the purpose of measuring its depth. As will be seen, it is much higher in the center than it is near the circumference. The time allowed for subsidence was about 33 minutes, and the deposit shown is the amount collected during a seven days' run of the filter.

The casting shown at the top of the view is the rotary deflecting elbow, secured to the central shaft below the standpipe, which is used when the subsidence basin is cleaned. The view also shows the main delivery pipe for the filtered water.

The four views on Plate II are intended to illustrate the theoretical side of the question. They were made from photographs which were kindly loaned me by Prof. W. P. Mason, of Troy, N. Y., and which were taken during an experiment conducted by him.

These views show the progress of subsidence in two jars of water during the experiment that I have just referred to. The jars differ from each other only in the fact that the one on the left had its contents gently rotated during the experiment, while the right-hand jar was maintained at complete rest. The same quantity of hydrate had previously been formed in each.

The views show how progressively advantageous was the rotary motion for the formation and deposit of large masses of hydrate. The first view was taken immediately before the rotary motion was commenced in the left-hand jar; the second shows the jars three minutes after the rotary motion was commenced; the third was taken six minutes after the rotary motion was commenced; and the fourth view, which completes the series, shows the jars ten minutes after the rotary motion was commenced in the left-hand jar, and shows that subsidence in the latter jar was somewhat further advanced than it was at the end of six minutes. It also shows that, apparently, there had not been any subsidence in the right-hand jar, in which the water had remained stationary during the entire experiment of ten minutes.

RESULTS.

Probably the most extensive test of a mechanical filter in practical operation that has ever been made in this vicinity was conducted during the months of March, April, and May, 1899, with the filter of the East Providence Water Company, at East Providence, R. I.

The average results obtained during this test, when sulphate of alumina was used at the rate of one grain per gallon, show that there was: —

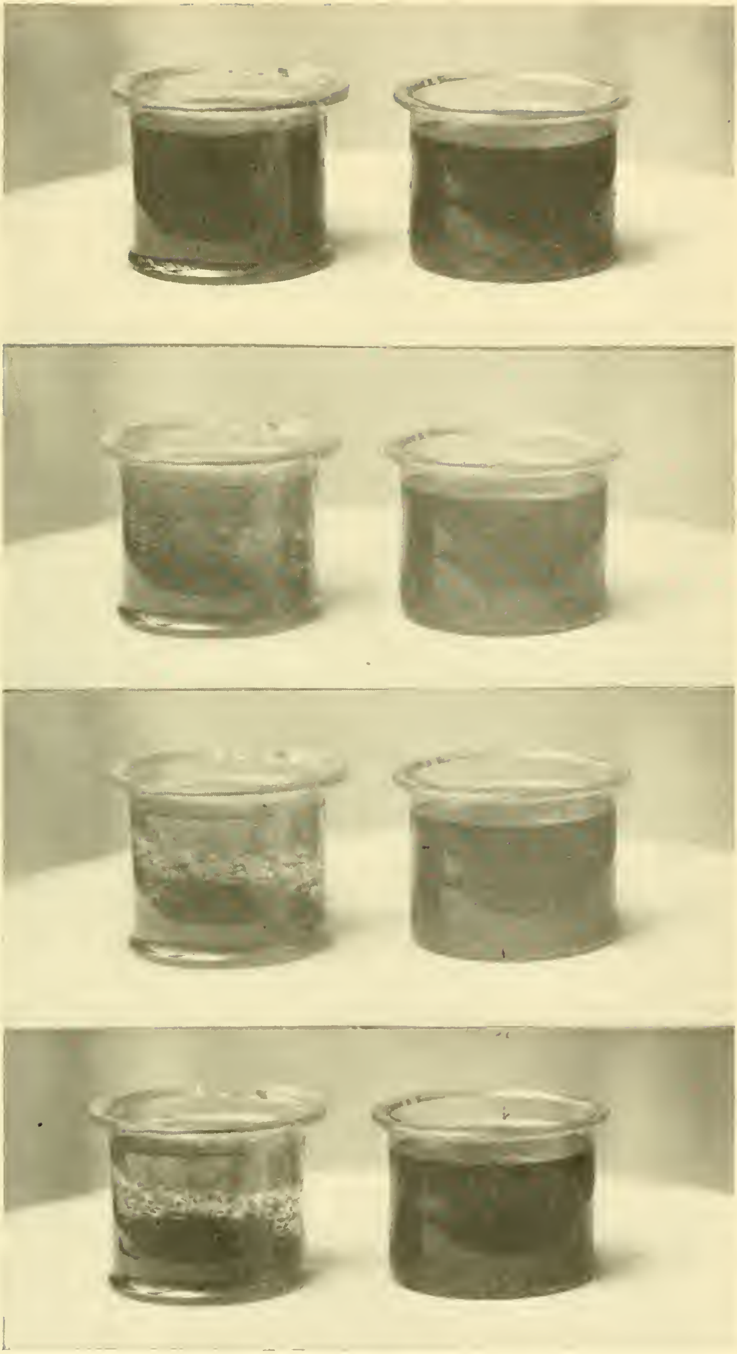
99.2% less bacteria in the filtered water than in the raw water;
6% less total solids;
1% less chlorine;
61% less ferric oxide;
38% less aluminic oxide (alumina);
29% less free ammonia;
63% less albuminoid ammonia;
83% less color;
20% increase of total hardness in the filtered water.

The filtered water in every instance was distinctly alkaline.

The increase in the total hardness, 20 per cent., is, of course, of no particular moment, as it is only equivalent, expressed as calcium carbonate, to 0.21 of a grain per gallon, and, relatively, the effect of so small an amount would not be noticed, either in the formation of boiler scale or in the quantity of soap used for domestic purposes.

The question is sometimes raised, in the course of preliminary investigations, as to the relation between the alkalinity of a natural

PLATE II.



PROGRESS OF SUBSIDENCE IN ROTATED AND QUIET WATER.

water and mechanical filtration. I will endeavor to state briefly my understanding in regard to it.

Alkalinity is generally expressed as calcium carbonate or carbonate of lime. When a proper quantity of sulphate of alumina is added to a natural water containing an alkaline substance, for example, carbonate of lime, an exchange takes place. Instead of sulphate of alumina and carbonate of lime, there is produced carbonate of alumina and harmless sulphate of lime. But the carbonate of alumina immediately decomposes, giving off carbon dioxide, and forms aluminum hydrate, which acts as a coagulant, as I have before stated.

I am led to believe, more especially in regard to New England natural waters, that reliable experimental results are much more satisfactory than theoretical computations for drawing conclusions as to the relative alkalinity that it is requisite for a natural water to have in order for it to properly act with the added sulphate of alumina.

At East Providence the sulphate of alumina used during the test contained about 22 per cent. of alumina (Al_2O_3). The alkalinity, expressed as calcium carbonate in parts per 1 000 000, during the test averaged 11.9 for the raw water and 4.6 for the filtered water. The average alkalinity of the raw water in March was 7.1, in April 11.0, and in May 14.4.

In every instance during the test, as I have already stated, the filtered water was distinctly alkaline, and therefore showed that more sulphate of alumina could have been added to the raw water than the one grain per gallon that was used.

As it may be of interest, I will call attention to the alkalinity of the water supplies of Pawtucket, R. I., and Providence, R. I., which was determined during March, April, and May, 1899, coincident with the analyses that were made of the raw water at East Providence, for the purpose of comparison.

The total average alkalinity of samples of water from the intake at Pawtucket during the three months was 12.2. The average for March was 7.8, that for April 11.9, and that for May 15.1. As can be seen from these figures, the alkalinity of the Pawtucket raw water was somewhat greater than that of the raw water at East Providence.

The total average alkalinity of samples of water from the settling basin of the Providence water works, which is supplied with water

from the Pawtuxet River, at Pettaconset Pumping Station, during the three months was 8.8. The average for March was 5.2, that for April 8.7, and that for May 10.2. These figures show that the alkalinity of the Providence raw water was less than the alkalinity of the East Providence and Pawtucket water. It is possible, however, that if the samples of water had been taken from the Pawtuxet River itself instead of from the settling basin, a higher alkalinity would have been obtained, as there are several large springs at the bottom of the settling basin.

The question is sometimes asked if mechanically filtered water will injuriously affect steam boilers and iron pipes.

As a matter of fact, there are in the United States alone more than 127 mechanical filter plants in operation, purifying the water supplies of cities and towns. These represent a total daily capacity of more than 220 000 000 gallons, yet I have never heard of a case where the mechanically filtered water has in any way injured steam boilers or iron pipes.

The quantity of sulphate of alumina used in purifying a water is relatively very small. It may be said that, on the average, it ranges from ¼ of a grain to 3 grains per gallon, dependent upon the character of the water — and the character of the water is generally dependent upon the place. At East Providence the maximum amount used is 1 grain per gallon.

Some persons have feared that the use of mechanically filtered water might in some manner be injurious to health. I would say that I have never known of an instance of this kind.

In August, 1898, Dr. Gardner T. Swarts, Secretary of the State Board of Health of Rhode Island, sent circular letters asking for information in regard to the use of sulphate of alumina, to the health officers of different cities and towns where mechanically filtered water is used. Among the questions included in each circular letter was the following : —

"Has any sickness among the users of water been attributed to the sulphate of alumina in the water?"

The number of replies received to these circular letters from cities and towns where sulphate of alumina or alum had been used from about 1 to about 17 years was 44 ; and the reply to this question in every instance was in the negative.

Practically all natural waters appear to contain in solution some compound of alumina.

Several years ago a sample of sulphate of alumina weighing one half of a grain was analyzed. At the same time a sample of Pawtuxet River water, which is the source from which the city of Providence obtains its supply, was analyzed. The results indicated that the sample of Pawtuxet River water contained in solution, per gallon, 37 per cent. as much alumina (Al_2O_3) as the sample of sulphate of alumina.

It has sometimes been stated, apparently as a sort of bugbear, that mechanically filtered water may contain sulphuric acid. This statement is probably based upon an ambiguous use of the term "sulphuric acid." Such a water may contain sulphates, but these are not sulphuric acid, although they may be considered as representing it. These sulphates are harmless. They are present in the Pawtuxet River water, and can probably be found in nearly all natural waters.

The Commission to Investigate the Extension and Improvement of Philadelphia's Water Supply, in a report dated September 15, 1899, state in regard to mechanical filters, to the effect: By virtue of some operation not yet thoroughly explained, mechanical filters appear to be able to secure equally as satisfactory bacteriological results as slow sand filters, although filtering at from thirty to fifty times the rate. In other words, for a quantity of water requiring from thirty to fifty acres of filter beds by the slow sand process, one acre of surface of mechanical filters would suffice, provided the conditions of the given case were equally favorable to the two systems.

COST OF FILTRATION.

I have quite recently estimated \$4.73 per million gallons as the cost of operating and maintaining a mechanical filter plant of 15 000 000 gallons per 24 hours available capacity, while using 0.6 of a grain of sulphate of alumina per gallon, and including interest and sinking fund, etc., namely: —

Sulphate of alumina, 0.6 of a grain per gallon, at \$1.25 per 100 pounds, for water and wash water	\$1.13	per million gallons.
Labor and fuel, etc.	1.63	,, ,, ,,
Interest, sinking fund, etc.	1.97	,, ,, ,,
	\$4.73	,, ,, ,,

DISCUSSION.

The President. The discussion of Mr. Weston's paper will be opened by Dr. Gardner T. Swarts, Secretary of the State Board of Health of Rhode Island.

Dr. Swarts. It is with considerable diffidence that I enter upon this discussion; but, as I presume I am merely a valve-opener for what will come afterwards, I may be excused if I do not go into the detail of this subject as thoroughly as may be done by others who will follow me. My diffidence comes from the fact that there are persons here with us this afternoon who can speak with high authority, and whose experience with mechanical as well as sand filtration is so far in advance of my own that any allusion to the comparative values of this form of filtration and any other, or to the certain peculiar processes which have been spoken of in the paper, and the various matters of detail, can perhaps be better made by them than by me.

But speaking from the standpoint of the public health, I think I may be justified in saying that there is no question which is of more importance to us as health officers and to you as engineers and water works men than this subject of filtration. Fortunate is the city or town that has been able to find within a proper district, at a proper distance from its pumping station or from its center of population, a supply of water which is pure in every particular. If we have to go a long distance to get pure water the expense is so great that we are led, perhaps, to take water from a nearer source, although the quality may not be so good. We have, perhaps, already established a water supply, and too late in the day we find that our dear neighbor above us has had water before and found it must get rid of its wastes and is emptying its sewage into the source from which we take our supply. Of course they have no right to do that, and we have a legal redress, but by the time that can be availed of perhaps the mortality statistics will be increased within our own town to an alarming extent. And we are perhaps justified then in availing ourselves of some means whereby we may purify the water so that we can continue to use it, although it is not as pure as it ought to be in the beginning. And it is by such means as those which have been shown here this afternoon that such a result may be effected.

From what we have heard in the paper it appears that mechanical filtration does, can, and will purify a water which is badly polluted.

As has been stated, an efficiency of 99 per cent. is secured in the removal of bacteria, and that, gentlemen, when we consider that there may be from 3 000 to 6 000 bacteria to a cubic centimeter, and even more, is something worth considering. The number of bacteria may not, of course, represent absolute danger at the time when the bacteria are introduced into the supply, but it means that at some time or other, if there is pollution, there may be organisms which will be dangerous to those who drink the water. Of course we look upon the danger as being principally from typhoid fever or from cholera, two things which perhaps are not so common as we might expect; but the fact that a certain amount of pollution is present indicates that there are other bacteria, which are in the waste products of the human system, as well as the results of decomposition of materials which are going into the sewage of the towns above us and finding their way into our water supplies, or which are being thrown upon the land in the form of fertilizers and thence are washed into our reservoirs, and which we cannot control. And many of those germs, finding their way into the intestinal canal of a human being, will eventually produce, in a debilitated state of the intestine, a form of fever and a form of disease, which, although it may not be true typhoid fever and may not always be due entirely to the presence of the *Bacilli Coli Communis*, will yet produce a condition within the intestine which may result in what we call slow fevers — fevers of indefinite diagnosis which will be sufficiently disturbing to keep us from our business, or reduce our ability as citizens who should be carrying on our business in a proper manner; and such sources of pollution, of course, should be removed. And if it is possible by mechanical or any other form of filtration to so remove that material, of course it is our duty as health officers, as civil engineers, and as water commissioners, to recommend that some system of the sort should be adopted.

The question is not whether we can stop the pollution so much as it is whether we can reduce it by means of purification. And this question does not come alone to us as health officers and as civil engineers. It comes also to individuals who are owning private water supplies, and at times when they are in such a financial condition that they do not care to go to the expense of the purification of the water. They are always liable, even when they have obtained a source of supply which was originally pure, to danger from some new town locating above that supply and polluting the water. And

to them this subject is of much interest. And it is of interest to us as health officers, who must demand from these private corporations that are selling water, or from any city that proposes to sell water, that they shall sell the best that can be had or produced from available sources.

Now, we are assured, and we will assume and believe that water may be purified by mechanical filtration to the extent stated. But the bugbear which is brought up to us by the laity, that is, by the people at large, and by many physicians who have not looked into the subject thoroughly, is that there is great danger that we are going to get alum into our intestinal canals and our stomachs, that we are to be ossified in time, that dire results are to occur as the result of the constant ingestion of alum into the system. If we look back to the time when we were boys, when some of us had the habit of chewing gum and perhaps some other bad habits, we may remember that it was the custom of some boys to carry chunks of alum in their pockets and to chew from them from time to time. I do not remember during my medical experience personally, or from any literature which I have read, to have observed any ill results coming from the use of alum in its crude state.

And, as has been stated in the paper, with a view of determining for the city of Providence whether it was safe to recommend mechanical filtration as a means of purifying the water for that city, I communicated with some thirty or forty different cities, requesting the opinions, not of owners of filter patents or filter plants, not of the mayors or the boards of aldermen, but of the health officers, the disinterested parties who should know of these matters, asking them if they had ever heard of any injury coming from the use of alum in the water, where it was being used in this form of filtration. In no single instance was an affirmative reply received. It was even stated by some that although they were aware that at times there were large quantities of alum in the effluent water, yet they had never known of any disease which they could attribute to that cause. In fact, I have been unable after questioning my various medical friends, and chemists who are also physicians, to obtain any knowledge as to what would actually be a poisonous dose of alum. I have not been able to find any one who would say that even one grain of alum per gallon, if taken in that quantity, was injurious to anybody. Of course it may be objectionable to the taste, and there would be an objection to the use of it by certain persons; but we are informed

that by this means of filtration, if it is properly carried out, no alum passes through the filter into the effluent. The statement is made, and it is confirmed by many experimenters, that there is frequently less alum in the filtered water than there is in the original water before it goes into the filter. Of course that is a statement which ought not to be made too publicly, because it would be said the thing is altogether too perfect, and the statement would be characterized as a little fishy.

As a matter of fact, we want to come down to the practical question, can this system be used? There may be other systems which are good, and all may be of equal value; but in using this system the question is, can we use it with safety? As a health officer, I do not hesitate to recommend this form of filtration, judging from the reports which have been given of the various experiments made by many men who are here to-day, experiments made at Louisville, Cincinnati, Pittsburg, and other places; and I do not think that any of you would hesitate, after looking over the matter, to recommend the system in the same way.

As to the questions of cost or of operation, of course I am not prepared to state. As to the practicability of it, from the numerous illustrations we have had here it would seem that mechanically there can be all manner of devices and wheels and cogs and methods of applying the alum and all that, and that should not be an obstacle. Of course the question of the application of the alum is a thing which has to be considered in the operation of the plants. That, of course, must be accurate, and it can be made accurate, as I believe has been shown; and if that is the case, I see no reason why we should not consider the system favorably.

Mr. George W. Fuller. I have listened with a great deal of pleasure to Mr. Weston's paper. I think it is about the first time there has been presented to this Association a paper describing in detail the construction and operation of the type of filters of which this system is representative. Owing to the lateness of the hour, there are very few points which I have time to bring up to-day. There is one feature, however, which attracted my notice as the paper was read and the views were presented on the screen, and that is the automatic controller. There is no doubt of the advantage, from many points of view, of having the rate of filtration under accurate control, and this controller which has been designed by Mr. Weston appears in every way to serve this purpose in an admirable

manner. I understand from the paper that this gives practically a constant rate of filtration when the head on the controller ranges from 18 feet down to 0.33 of a foot; and I would like to ask Mr. Weston if the uniformity in the rate and the accuracy of the results are maintained as this small head is secured upon the butterfly valve. That 0.33 of a foot refers to the pressure on the butterfly valve, does it not?

Mr. Weston. The 0.33 of a foot represents the distance above the water line in the controller.

Mr. Fuller. What pressure would that be on the butterfly valves?

Mr. Weston. When the head is 0.33 foot above the water line in the controller, I should say it would be about 4.5 pounds upon each valve.

Mr. Fuller. Another point is with reference to the effect of the rotary movement of the water in this type of a settling basin. Theoretically there is no doubt that the rotary action accomplishes a good deal towards aggregating these particles into larger masses and doing it more quickly than quiescent subsidence, or subsidence in the absence of this rotary movement. The question of how much practical good is accomplished in this manner is a matter which is not clear to me, especially with different kinds of water. It is a matter of a great deal of interest, and if Mr. Weston can give us more information upon that point I think it would be very much appreciated.

Mr. Weston. I think Mr. Fuller is as conversant with that subject as I am, and what experience I have had I have given to you.

Mr. Fuller. You mentioned, I believe, the figures from 40 to 60 per cent. of removal of suspended matter. Was that with this rotary motion?

Mr. Weston. I beg your pardon. I stated that it had been estimated that from 50 to 75 per cent. of suspended impurities are caught in the subsidence basins. It was found at East Providence that there was removed in passing through the subsidence basin from 60 to 88 per cent. of the bacteria, averaging about 75 per cent. So far as subsidence is concerned, my personal experience has been mainly with Eastern waters.

Mr. Fuller. So far as I know, there has never been any opportunity to compare directly and side by side with the same water, to say nothing of comparable data for a wide range of waters, the effi-

ciency of quiescent subsidence and subsidence under the rotary movement, which is supposed to aggregate more rapidly the suspended particles. While the latter may accomplish a great deal of good, to me it is a matter of considerable doubt from a practical standpoint, although not at all so when considered theoretically.

Dr. Swarts spoke with a great deal of truth, I think, and a great deal of clearness, on the question of undecomposed alum appearing in the filtered water. I can hardly agree with him in all particulars, however, although my opinion, so far as I have been able to study the evidence, coincides in general terms very closely with his. That is to say, in the 130 or more purification plants in operation in this country, using this general type of filter, there seems to be no evidence, so far as I have been able to learn, of their getting into trouble from having undecomposed alum in the filtered water. There are probably times when the alum might be present to a very small degree, if it were expressed in terms of greatest precision. And if we had means of finding out, perhaps, what its exact action in minute quantities would be on service pipes of various metals, or in retarding digestion, our views might be modified. But whether a certain kind of food is digested in sixty-eight minutes or seventy-four minutes is not a matter of vital consequence. The point to which I do attach the greatest importance, however, and upon which, perhaps, I am not exactly in accordance with Dr. Swarts' views, is the absolute absence, under all conditions and at all times, of the undecomposed alum or coagulating salt in the filtered water. In the great majority of the water supplies in this country there is probably very little doubt that this method could be used without getting any undecomposed alum in the effluent.

The question of the use of alum in connection with the water supplies of the East, in which the water is likely to be highly colored (due to dissolved organic matter), and where the alkalinity is fairly small, I think is a matter worthy of careful study. I believe that a great many people have a strong desire to have supplied to them from municipal water supplies a water which is lower in color than that which would be afforded by many Eastern supplies, even after filtration through sand filters. The question of how much color in filtered water is permissible in a water which shall be satisfactory to those who have a considerable appreciation of the æsthetic, as well as to those who wish to use the water for commercial purposes, for boiler supplies and street sprinkling, etc., I think is something

which this Association could discuss to a great deal of advantage. The Western waters have a great deal of silt and clay in them, and after that has been removed, as it is in a great many households by the use of Pasteur filters, they are practically colorless — not absolutely, but practically, colorless, and much freer from color than our Eastern waters. The Western people, in many instances, get accustomed to colorless water, and they are very much surprised at the color in our Eastern waters, and think there is an opportunity for improvement in that direction, independent of the quality of the water so far as it affects the public health.

It is quite interesting to note the points of view of gentlemen who are engaged in the water works business in different parts of the country, where the kinds of water are very different, and where the plants to purify the waters differ in many ways; and it occurs to me as a point which is to be borne in mind that those conditions which are satisfactory and those means which yield satisfactory results in one country, or one part of a country, will not necessarily do so in others. In considering the practicability of one method of water purification, or of one type of filter, it is to be borne in mind that while in many cases it might serve very admirably, in others it might not. In connection with this type of filter, which has been so well described by Mr. Weston, I must say it certainly is entitled to a great deal of credit because of its successful operation in a large number of cities and towns in the country during the last few years. It has been shown, not only by careful tests conducted with such scientific accuracy as can be commanded at the present time, but also in the actual filtration of water for many of these towns, that it is worthy of careful attention. Whether it can be successfully operated in certain parts of the country, in Florida or Maine or New York or Missouri, depends largely upon the water with which it has to deal. We must adjust our means of purification to the water we have to deal with.

Mr. R. S. Weston. I think we have all been very much interested in hearing of these later developments, representing the latest designs in the mechanical system of water purification. I think Mr. Weston will support me in saying that no one design of filter can be applied to all conditions. For instance, a filter which will handle the muddy water of the Ohio River certainly will not handle, with the same method of operation, the highly colored water of Maine, or of some of the tamarack swamps of north-

ern Wisconsin. I cannot see, and I think Mr. Weston will bear me out in this also, that a standard design of filter is a thing to be desired, any more than a standard design of pump. We expect to have a pump for high service and a pump for low service, and we should expect to have a filter for muddy water and a filter for highly colored water, and perhaps a filter for clearer water containing sewage pollution and the bacteria which cause disease.

There are a few things in the design which especially need to be varied to meet local conditions. One of the principal things which suggests itself to my mind at present is the size of the settling basin. This settling basin is the basin in which coagulation takes place. It is the basin, in other words, in which the sulphate of aluminum acts upon the particles of clay in the water, bringing them into aggregates, or it acts upon the dissolved clay in the water, making the dissolved clay unite with the precipitated hydrate of aluminum, or it is the place where the heaviest particles in water are deposited. Therefore, as waters vary in composition, the settling basin, I think, should be of a size adapted to local needs. For instance, I found in experiments which I conducted last year for the Superior Water, Light and Power Company, in Wisconsin, that a period of coagulation of twelve hours using four grains of sulphate of aluminum per gallon of water was not sufficient to satisfactorily coagulate the water. In recent experiments in Washington, D. C., under the direction of Lieut. Col. A. M. Miller, we have found that a period of fifteen minutes often suffices. This goes to prove that the basin must be adapted to the local conditions.

In Mr. Weston's design, the effluent often runs into an open conduit, without any protection against particles of outside pollution from careless workmen, etc. I do not see why our plants cannot be designed so as to obviate this danger. Personally, I prefer the introduction of the coagulant by gravity into the filter, and I think Mr. Weston has shown a very ingenious device for accomplishing this end. I think we are indebted to him for his paper.

Mr. E. B. Weston (by letter). I have already stated in my paper, namely: "For water containing large quantities of suspended matter like some Southern and Western waters, a longer time for subsidence is required than can be had in the filters. This is accomplished by using one or more auxiliary subsidence basins, built independent of the filters proper, of such capacity as the conditions of the case may necessitate."

All of the open flumes that have been shown are arranged so that they can be covered or arched over. I have found, by experience, that when it can be satisfactorily accomplished, open flumes are the most popular with water works officials, as the filtered water can then be seen as it is discharged and flows away from the filters.

ELECTROLYSIS FROM FACTS AND FIGURES.

BY E. E. BROWNELL, ELECTRICAL ENGINEER, DAYTON, OHIO.

[*Read January 10, 1900.*]

The subject of electrolysis from the grounded currents of the single trolley system of electric street railways is one that has recently been very generally discussed, and many plans have been proposed to overcome this destructive action which is to-day so threatening to our water works. None of these plans has ever fully materialized, and it is with some hesitancy that I present this paper before your Association, from the fact that so much has been said and so little done. I therefore wish to call your attention to this important subject in as practical a manner as possible, not in behalf of any corporation or municipality, but upon the merits of the case, as shown by facts and figures obtained from my own experience.

It is an undisputed fact that unless radical measures are adopted by the electric street railways in caring for their return currents, *electrolysis will occur* upon the piping systems wherever the single trolley system, or that which depends upon the rails for return conductors, is used.

Until recently it has been considered that the part of a piping system which was of a higher electrical pressure than, or positive to, the return conductors of the street railway system was the only part that was in immediate danger from electrolysis; but recent investigations have proved that even in the negative area serious electrolytic action has taken place upon cast iron pipes at the joints, and also upon the lead calking, and its effects are especially noticeable upon the surface of contact between the lead calking and the pipe.

It is not the intention of this paper to condemn the street railways, but only to present the actual conditions under which the ordinary electric road is now being operated; and these show that the destruction and resulting dangers are due to defective electric street railway construction. A brief consideration of the present method of construction of the return circuit will show some of the reasons why the current escapes from the rails. When large rails are perfectly bonded

electrically at the joints they offer an easy path, as return conductors, for a current of several thousand ampères, but poor bonding as a general thing results in making them very poor conductors. For instance, a 90-pound girder rail is usually bonded with from one to three .0000 copper bonds, while to make the conductivity of the bond equal to that of the rail would require at least nine .0000 copper bonds, even if perfect electrical contact between bond and rail were obtained. I have found from my own tests upon thirty-seven different electric street railways that the conductivity of the bond varied from 15 per cent. of that of the rail down to zero. In four cases, where the cast-weld joint had been very recently introduced, the conductivity of the joint was 7, 8, 9, and 11 per cent. of that of the rail.

The electrical resistance of a 6-inch water main is found to be 145 times that of a perfectly bonded 90-pound rail, or 580 times that of a double track (four rails) ; a 20-inch main has 12 times the resistance of the rail, or 48 times that of the double track ; and a 36-inch main 2.7 times that of the rail, or 10.8 times that of the double track. In these three mains it was found that an average of 87 per cent. of the total resistance of the pipe lines was in the joints, due principally to the poor electrical contact between the iron and the lead. The maximum resistance of a joint in a 6-inch water main was found to be 0.0367 ohm, or equal to that in 102 lengths (1 224 feet) of the pipe itself.

Plate I, Fig. 1, shows a 90-pound rail with a copper bond of the size necessary to offer no more resistance than the rail itself, *i. e.*, .00 000 545 ohm per foot ; also a 6-inch water main, having a resistance of .0003 ohm per foot for the straight pipe.

The resistance of cast iron has recently been shown to be 56 times and that of lead 12 times as much as that of commercial copper. The first of these values was obtained by Prof. Lucien I. Blake, of Kansas City. It is evident, therefore, that a pipe line ought to be a much worse conductor than the track. In fact, to offer no more electrical resistance than a double track laid with 90-pound rails perfectly bonded, a pipe would need to be large enough to drive a team through. Regarding the possibility of constructing a rail bond of a conductivity equal to that of the rail, it may be said that there is at least one bond (the Edison & Brown) which is guaranteed to offer no greater resistance than the rail itself.

The following are a few examples of the actual conditions existing at present.

In one Indiana city, where four 90-pound rails were found by measurement near the power house to be carrying not over 200 ampères each, the loss of potential in four miles was found to be 145 volts. With perfect bonding this should not have been over 23 volts, and probably not over 20 volts, allowing for the decrease of current as the distance from the power house increased. In another part of the same city, where the rails should be carrying a current of some 500 ampères, only 15 ampères could be accounted for. What became of the rest of the current?

In another city in Indiana the rails were found to be returning no current at all, on account of insufficient bonding.

In a certain city in Michigan, the inadequately bonded rails are supposed to care for a return current which amounts, as a momentary maximum load, to 13 000 ampères. This is certainly an imposition.

Figs. 2 and 3, Plate I, show the effects of shunted circuits around the joints of cast iron gas mains. The pipe in Fig. 2 was carrying a current of 50 ampères, and was 1 volt negative to the rails and 1.2 volts positive to the water pipes. The pipe in Fig. 3 carried a current of 120 ampères, was neutral to the rails, and 1.2 volts positive to the water pipes.

The figures on Plate II show the effects of electrolysis upon water pipes. Fig. 1 shows a 6-inch pipe which was 3 850 feet from the power station, and positive by 1.2 volts. The pipe was softer than lead, but contained only one hole. Fig. 3 shows the condition of several miles of water main in Dayton, Ohio, recently abandoned; the pipes were positive, from 5 to 7.2 volts, and carrying a current of 320 ampères. The deterioration was so bad that in places 6-inch pipes weighed less than 10 pounds per foot. Fig. 2 shows the effect of electrolytic action around a screw joint in a wrought iron or steel pipe. This pipe carried a current of 30 ampères, and was 150 feet distant from the street railway and negative to it. The resistance of this joint is equal to that of 2.8 feet of the straight pipe.

It is indeed questionable whether a single trolley electric railway system, in a city as large as Detroit, for example, can ever be provided with a satisfactory return system without incurring an expense sufficient to completely install an insulated return circuit, such as is used in the double trolley system, and thus remove all liability of further electrolytic action.

Take the case of a double track laid with 90-pound rails perfectly bonded, and a 36-inch water main parallel to the track, 5 feet below

the surface and 8 feet from the nearest rail. The water main would even in this case return 10 per cent. of the total current of an ordinary electric railway, with no other pipes in the street. With a wrought iron gas pipe of the same size, having screw joints and under the same conditions, it is safe to say that from 30 to 40 per cent. of the current would follow the pipe, although the resistance of the screw joint is equal to that of 2.8 feet of straight pipe. It is therefore evident that something more than perfect rail bonding is necessary; some sort of a return feeder system of still lower resistance is required, if the single trolley system is to be maintained without injury to gas and water pipes.

The main object should be to keep the pipes as much isolated from the rails and return circuits as possible. Under no consideration whatever should the pipes be metallically bonded to the rails or to the negative pole of the dynamo; for if this is done a larger portion of the current is induced to return by the pipe, as the total resistance by that route is thus decreased. Trouble will then result where the current passes from the pipe to the rail or from one pipe to another, and also from shunted circuits around each joint.

Very serious results have ensued in negative areas where it was until very recently supposed that no danger existed. In Indianapolis the water pipes have the lowest potential but highest resistance of any of the return conductors. Thus it frequently happens that a current is flowing from the gas pipes to the water pipes. The resulting electrolysis upon the gas pipes has caused very serious damage, and not alone in streets used by the electric railway. The highest difference in potential noted between the gas and water mains was 4.2 volts.

The greatest objection to allowing any piping system to act as a return conductor, if it is negative to all other return conductors, is that electrolysis will take place at the joints. I have noted this action in the negative district in sixteen cities. In some cases the pittings were extensive, and reached to one half the thickness of the metal.

From records kept in six different cities, it appears that 97 per cent. of all the leaky joints occurred where the pipes were carrying considerable current.

I have several times noticed the serious effect of electrolysis upon the interior of cast iron pipes. These cases, however, occurred only where the pipes were suspended in the air or surrounded by a dry, sandy soil, and it is evident that the path of least resistance for the current around the joint was through the water in the pipe.

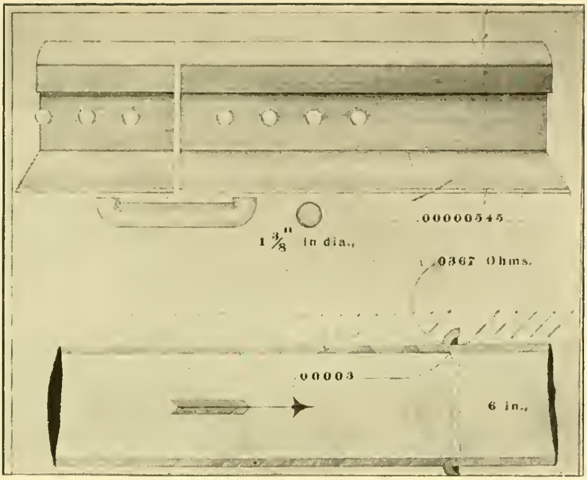


FIG. 1.—RELATIVE RESISTANCES OF 90-LB. RAIL AND 6-IN. WATER MAIN.

FIG. 2.—EFFECT OF ELECTROLYSIS ON CAST-IRON GAS MAIN.

FIG. 3.—EFFECT OF ELECTROLYSIS ON CAST-IRON GAS MAIN.

Doubtless you are all familiar with the fact that a pipe line which is electrically positive to the return conductor of the electric railway is in a very dangerous electrical condition, and trouble is sure to result sooner or later. Lead has been destroyed under an electrical pressure of 0.01 volt, and cast iron under 0.5 volt. Notwithstanding this, some theoretical writers still say that "cast iron, particularly those varieties that contain large amounts of carbon and silicon, known as white cast iron, are so little affected as to be almost exempt." As a matter of fact, a cast iron water pipe in Dayton, Ohio, 3 800 feet from the power house, was so affected as to be softer than lead. (See Fig. 1, Plate II). Indeed, the destruction to gas and water pipes throughout the West is enormous, and there is little prospect of any improvement in the conditions.

It appears that all of the methods employed by the single trolley electric roads have proved failures. Ought we now to remain quiet while they experiment with a thousand and one other and equally as unsatisfactory arrangements? The street railway companies have not invested and, it seems probable, will not invest the necessary capital to fully protect the pipes unless forced to do so. It is the part of wisdom in a water works manager to insist upon the removal of these dangerous currents from his pipes as soon as electrical tests show them to be present, and not to wait until their destructive effects are proved by serious damage to the mains.

DISCUSSION.

Mr. Charles H. Morse * (by letter). I have read with much interest the paper of Mr. Brownell. There can be no doubt that the single trolley street railways are working great injury to the underground pipe systems of our cities. In order to reduce this danger to a point which should be tolerated, an immense amount of return wire must be installed.

I have just learned that in the city of Washington, D. C., the government has taken a wise stand, and has compelled the railway companies to install a complete metallic circuit, — a double trolley system. The suggestion has been made that a three wire system, so called, might be used, — that is, have part of the system connected so that the trolley would be positive to the earth and another section negative; by making these zones of small area the ground

* Cambridge, Mass.

would be neutral and the pipes and rails would carry little current. The Edison Lighting Companies use this system for incandescent lighting, and make a great saving in copper.

Something must be done, and will be, if not voluntarily, then through legislative action; but not until hundreds of thousands of dollars' worth of pipe have been destroyed.

A double trolley system will completely remedy the evil.

Mr. W. E. Foss * (by letter). The large main pipes of the Metropolitan Water Works traverse nearly all of the cities and towns located within ten miles of the State House in Boston. During the past four years, while laying these mains, very favorable opportunities have been presented to study the subject of electrolysis, and to learn much from experience about the stray currents of electricity from the street railways, — the currents causing the electrolytic action which is stealthfully destroying the underground piping systems.

As a result of this study and experience it is my opinion that it is good practice to keep the pipes as much isolated from the rails and return circuits as possible, as suggested by Mr. Brownell. I believe, however, that the main object should be to keep the stray electric currents out of the ground.

The electrical resistances given for the several pipe lines are of much interest. It would also be interesting to know about the method of measurement by which the resistances were obtained.

When the study of this subject was begun on the Metropolitan Water Works, in the fall of 1896, it was seen that a knowledge of the electrical resistances of pipe lines of various diameters would be of value. Measurements to determine these resistances have been made at all favorable opportunities.

Although the resistances of pipe lines in which no attempt has been made to obtain a uniform electrical contact at the joints vary largely in different lines of the same diameter, and even in different portions of the same line, the results which have been obtained on the Metropolitan Water Works may be of interest. They are as follows: —

* Assistant Engineer, Metropolitan Water Works.

ELECTRICAL RESISTANCE OF CAST-IRON PIPE WITH LEAD JOINTS.

Diameter of Pipe. (Inches.)	Resistance. Ohms per 1 000 feet. (Approximate.)	Remarks.
12	.021	New pipe, never filled with water.
16	.027	" " " " " "
16	.060	Full of water, in use 6 months.
20	.020	" " " "
24	.028	Empty, in use 18 months.
36	.012	New pipe, never filled with water.
36	.029	" " " " " "
36	.035	" " " " " "
48	.004	" " " " " "
48	.016	Full of water, in use 6 months.
48	.018	New pipe, never filled with water.

All the measurements were made on the pipes as laid in the ground. The method of measurement was in all cases to cause a measured quantity of electricity to flow to or from the pipe, and measure the drop in the voltage occurring in a known length of the pipe line. The quantities of electricity used in making these measurements varied from 10 to 140 ampères.

While laying pipe lines, currents of electricity of from 20 to 100 ampères have been obtained by connecting the ends of sections with a No. 8 copper wire before the sections were united. At the point where the largest current was measured, a wire nail one tenth of an inch in diameter was heated to a white heat when placed between the ends of the 48-inch pipes before the sleeve used in making the closure was put on. These facts give us an idea of the magnitude which has already been reached by the stray electric currents from the street railways.

It is with much interest that I learn that it is the opinion of an electrical engineer that it is questionable whether a single trolley electric railway system, in a city as large as Detroit, can ever be provided with a satisfactory return circuit without incurring an expense sufficient to completely install an insulated return circuit. My own experience and study have convinced me also that such is the case.

I have in mind a district containing about 800 000 inhabitants, in which the average current supplied to the street railway system is about 15 000 ampères, and reaches a maximum at times during the day of 20 000 ampères in summer and possibly 50 000 ampères in

winter. As a return path for this current there is as much as 250 miles of single track, laid with heavy rails thoroughly bonded, and in addition probably the equivalent of 200 miles of copper cables with a sectional area of 500 000 circular mills. In the portions of this district most remote from the power stations the rails are from 6 to 10 volts positive to the large water pipes, and from 2 to 3 volts positive to the smaller pipes. Near the power stations the pipes are positive to the rails by about the same amounts.

Can this dangerous condition be remedied by the method which is receiving the most attention at the present time, that of providing additional return paths for the current?

Assuming that the 250 miles of single track are equivalent to 1 000 miles of copper cable with sectional area of 500 000 circular mills, to double the present return system would require 1 200 miles of such cable, which would cost about $2 000 000. As a result of this outlay, the difference in potential between tracks and pipes would probably be reduced to about one half of the differences existing under present conditions. Would this result be considered a satisfactory solution of the problem? All that would have been gained from the outlay of this large sum of money would be that the danger had been moderated to some extent.

It appears that the acute danger can be somewhat relieved by this method, but so long as the current is allowed to be discharged freely into the earth in such large quantities, it is not practicable to prevent electrolysis completely in this way.

Mr. Brownell's opinion in regard to an insulated return system would be of interest. Is it practicable to install and operate such a system for a city of 500 000 inhabitants?

The high resistance of the cast-weld joints obtained by Mr. Brownell is remarkable. I am informed that the resistance of this bond where it has been put in properly in cold weather is no greater than that of the rail.

Mr. E. E. Brownell (by letter). Since reading the foregoing paper, various questions have been asked, especially about the resistance in ohms of the various-sized piping systems and joints, which, with other accompanying data, will perhaps be of much interest.

The electrical resistance of any piping line, in streets with other parallel conductors, such as gas and water mains, with their service pipes, can never be obtained to any marked degree of accuracy. Moreover, the resistances of gas mains of like material and size are

FIG. 1.—EFFECT OF ELECTROLYSIS ON 6-IN. WATER MAIN.

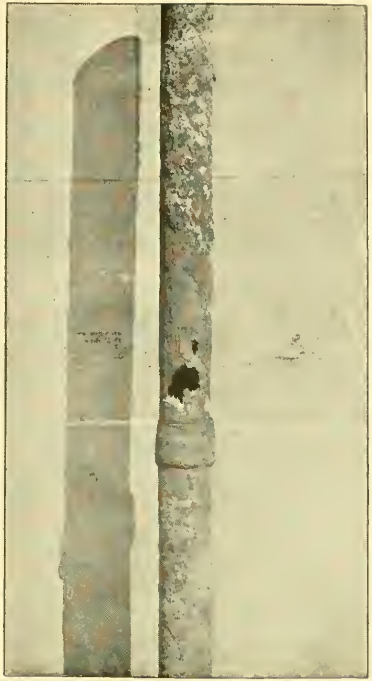


FIG. 2.—EFFECT OF ELECTROLYSIS ON WROUGHT-IRON GAS PIPE.

FIG. 3.—DESTRUCTION OF WATER MAINS IN DAYTON, OHIO.

from 10 to 15 per cent. higher than those of water mains. The resistance of the earth surrounding the mains is an important factor in increasing or reducing the resistance of any piping line having lead joints ; so is the character of the lead joint, where affected by electrolytic action.

Having very recently had occasion to remove a section of a water main, partially destroyed by electrolytic action, I found that 17 out of 19 joints were leaking very badly, showing a resistance of 22 per cent. higher than similar pipe not thus affected by electrolytic action.

The following tests have been carefully made at the expense of considerable time and money in securing conditions so as to get as accurate results as possible.

The current supply was taken from accumulators, using duplicated Weston instruments, just calibrated, and the most delicate manufactured. These pipes were *completely* isolated from any other conductors, and remote from any electrical influence of any kind, even to the grounding of a single telephone, the earth, which was a dry gravel soil, being the only variable included in the following tests. The pipes had been laid from five to ten years.

TABLE SHOWING AVERAGE ELECTRICAL RESISTANCE, ETC., IN CAST IRON PIPES OF VARIOUS SIZES.

Diameter of Pipe. (Inches.)	Loss of Electrical Pressure. (Volts.)	Quantity of Current. (Amperes.)	Electrical Resistance per 1 000 feet of Pipe. (Ohms.)
4	14.72	8.	1.84
6	8.89	11.2	.792
8	5.35	12.4	.432
10	3.32	12.1	.275
12	2.46	13.2	.187
16	1.26	12.2	.104
18	.988	12.2	.081
20	.819	12.6	.065
24	.504	11.8	.045
28	.369	11.1	.033
30	.319	11.0	.029
36	.168	11.2	.015

The above results are each the average of a series of ten independent tests, the greatest variation being less than four per cent. in each series of ten readings ; while the readings in a crowded street, with many other piping lines adjacent, varied from 20 to 300 per cent. in resistances.

All information upon this subject should come only from practice, otherwise it is worthless and only tends to mislead the public. Far

too much theory has already been submitted, with few or no facts to substantiate its correctness.

Local conditions cause different results in every city, or upon every piping line, so no specific rule will hold good in all cases, while a general one may.

In conclusion, it is my opinion, after having carefully tested over 187 systems, that the evils of electrolysis could be avoided with little difficulty, providing the necessary outlay of capital was allowed. Without this we must expect to submit to the great deterioration due to these stray currents, for years to come.

PROCEEDINGS.

QUARTERLY MEETING.

Young's Hotel, Boston, March 14, 1900.

President Cook in the chair.

The following members and guests were present: —

Members.

Charles H. Baldwin, Roland D. Barnes, James F. Bigelow, Lewis M. Bancroft, Frank A. Barbour, Joseph E. Beals, E. C. Brooks, James W. Blackmer, George F. Chace, G. L. Chapin, John C. Chase, Henry A. Cook, Byron I. Cook, Freeman C. Coffin, J. W. Crawford, A. O. Doane, B. R. Felton, John N. Ferguson, Z. R. Forbes, F. F. Forbes, Julius C. Gilbert, J. F. Gleason, W. E. Foss, J. A. Gould, Frederick W. Gow, E. H. Gowing, William R. Groce, E. A. W. Hammett, John C. Haskell, William E. Hawks, Horace G. Holden, F. S. Hollis, Frank E. Hall, F. G. Judkins, Willard Kent, Leonard P. Kinnicutt, Morris Knowles, James W. Locke, A. E. Martin, Leonard Metcalf, F. E. Merrill, Thomas Naylor, Horatio N. Parker, John N. Perkins, J. B. Putnam, A. H. Salisbury, Charles W. Sherman, J. A. St. Louis, George A. Stacy, Walter H. Sears, John D. Shippee, H. O. Smith, Solon F. Smith, William F. Sullivan, Lucian A. Taylor, Robert J. Thomas, William H. Thomas, Harry L. Thomas, D. N. Tower, George W. Travis, W. H. Vaughn, William W. Wade, Charles K. Walker, George E. Winslow, C. J. Youngren.

Associate Members.

Chapman Valve Mfg. Co., by George F. Hughes; M. J. Drummond, by Walter J. Drummond; Hersey Mfg. Co., by Albert S. Glover; Henry F. Jenks, Pawtucket, R. I.; Neptune Meter Co., by H. H. Kinsey; Rensselaer Mfg. Co., by Fred S. Bates; A. P. Smith Mfg. Co., by W. H. Van Winkle; Union Meter Co., by Frank L. Northrop; Walworth Mfg. Co., by B. Frank Polsey; The George Woodman Co., by H. A. Gorham.

Guests.

V. G. Barnard. Purch. Agent, Lowell, Mass.; Amos H. Eaton, Chairman, Middleboro, Mass.; John Greenleaf, Auburn, Me.; H. R. Johnson, Reading, Mass.; Leigh T. Macurdy, Watertown, Mass.; D. P. Mansur, Everett,

Mass.; R. A. Sears, Ex-Mayor, Quincy, Mass.; Everett U. Crosby, New York City; D. W. Cole, Melrose, Mass.

The following new members were elected: —

Resident Active. — D. W. Cole, Melrose; Frank E. Fuller, West Newton, Engineering Department Metropolitan Water Board.

Non-Resident Active. — Everett U. Crosby, of the North British Mercantile Insurance Co., of New York; Thomas H. Bennett, Superintendent Oswego Water Works, Oswego, N. Y.

Associate. — Henry N. Libbey, Boiler and Water Works Supplies, and manufacturer of the Libbey Drip Valve, Boston.

On motion of Mr. Holden, the President was requested to appoint a committee to nominate officers for the ensuing year, to report at the next regular meeting. The President announced that he would appoint the committee at some future time.

The President appointed as a committee on revision of the Constitution suggested by past President Forbes, to report at the September meeting, past President George A. Stacy, Charles W. Sherman, and Albert S. Glover.

On motion of Mr. Morris Knowles, the selection of the place for holding the next annual meeting was referred to the Executive Committee with full power.

On motion of Mr. Sherman, the thanks of the Association were extended to Mr. Forbes for the opportunity afforded to visit Brookline and witness his process of making cement-lined service pipe.

The first paper of the afternoon was by Everett U. Crosby of the North British Mercantile Insurance Co., of New York, his subject being "Eliminating the Conflagration Hazard." The paper was discussed by President Byron I. Cook and Messrs. E. C. Brooks, John C. Chase, J. C. Gilbert, George F. Chace, J. A. Gould, H. G. Holden, and R. J. Thomas. On motion of Mr. Holden, the thanks of the Association were voted Mr. Crosby for his paper.

Mr. J. C. Haskell, Superintendent of Water Works, Lynn, Mass., read a paper on "Public Water Systems *vs.* Typhoid Fever," which was discussed by Prof. L. P. Kinnicutt, Mr. George F. Chace, Dr. F. S. Hollis, and Mr. Morris Knowles.

Mr. Freeman C. Coffin, Civil and Hydraulic Engineer, of Boston, read a short paper entitled "A Few Notes on Cast Iron Water Pipe." It was discussed by Mr. John C. Chase.

Mr. C. W. Sherman read a paper by William Murdoch, Engineer and Superintendent of Sewerage and Water Supply, St. John, N. B., on "Wooden Joints in Cast Iron Water Mains."

Adjourned.

EXCURSION.

Previous to the meeting of March 14 a number of the members visited Brookline at the invitation of Mr. F. F. Forbes, Superintendent of the Brookline Water Works, to witness his process of lining service pipes with cement, which was described at the February meeting.

OBITUARY NOTE.

Nathaniel Dennett, for twenty-two years Superintendent of the Somerville, Mass., Water Works, died at his home in that city on February 21, 1900, from the effects of a stroke of paralysis. He was born in Portsmouth, N. H., January 26, 1828. During the Civil War he served as a member of Company B, 5th Massachusetts Volunteers. He was elected a member of this Association on September 19, 1883.

New England Water Works Association
MEMBERSHIP ROLL.

SEPTEMBER 1, 1899.

Note.—The Secretary requests to be advised of existing errors or change of address from that which appears in the following list.

ACTIVE MEMBERS—RESIDENT AND NON-RESIDENT.

Abbot, Everett L.
236 Eighth Avenue, New York City.

Adams, John D.
Superintendent Provincetown, Mass.

Allen, Charles A.
Civil Engineer, 44 Front Street, Rooms 109 and 110 Worcester, Mass.

Allen, Charles F.
Treasurer, Hyde Park, Mass.

Allis, Solon M., C. E.
Bell Rock Street, Malden, Mass.

Andrews, Frank A.
Assistant Superintendent, Nashua, N. H.

Appleton, Francis E.
Paymaster Locks and Canals Company, Lowell, Mass.

Armstrong, S. G.
Civil Engineer, Box 2139 Johannesburg, South Africa.

Ashwell, William H.
Civil Engineer, 76 Home Bank Building, Detroit, Mich.

Babbidge, P. F.
Superintendent, Keene, N. H.

Babcock, Stephen E.
Chief Engineer, Little Falls, N. Y.

Bacot, R. C., Jr.
Superintendent Meter Department, P. O. Box 461 Port Chester, N. Y.

Badger, Frank S.
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Badger, Wm. E.
Assistant Engineer, Locks and Canals Company, Lowell, Mass.

Bagnell, Richard W.
Superintendent, Plymouth, Mass.

Bailey, E. W.
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Bailey, Frank S.
State Board of Health, State House, Boston, Mass.

Bailey, George I.
Superintendent, 61 State Street, Albany, N. Y.

Baldwin, Charles H.
Box 2410, or 159 Franklin Street, Boston, Mass.

Baldwin, Richard.
Proprietor Water Works, Terryville, Conn.

Bancroft, Arthur G.
Civil Engineer, Box 506, Reading, Mass.

Bancroft, Lewis M.
Superintendent, Reading, Mass.

Barbour, Frank A.
Civil Engineer, 1120 Tremont Building, Boston, Mass.

Barnes, Roland D.
City Hall, Malden, Mass.

Barns, Everett.
Superintendent, Westerly, R. I.

Barrett, Albert P.
Woburn, Mass.

Barrus, George H.
Consulting Steam Engineer, 95 Milk Street, Boston, Mass.

Bartlett, Charles H.
Civil Engineer, 852 Elm Street, Manchester, N. H.

Bartlett, R. S.
Superintendent, Norwich, Conn.

Bassett, Carroll, Ph.
Treasurer Water Company, Summit, N. J.

Bassett, George B.
Civil Engineer. 363 Washington Street, Buffalo, N. Y.

Batchelder, George W.
Water Registrar, Worcester, Mass.

Batcheller, Francis.
Commissioner, North Brookfield, Mass.

Bates, Oren B.
Clinton, Mass.

Bates, Theodore C.
29 Harvard Street, Worcester, Mass.

Battles, James M.
120 Marginal, cor. Cottage Street, East Boston, Mass.

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Beasom, C. B.
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Benzenberg, G. H.
City Engineer, 346 Jefferson Street, Milwaukee, Wis.

Berkey, John A.
President Electric and Water Company, Little Falls, Minn.

Bettes, Chas. R.
Chief Engineer Queen's County Water Company, Far Rockaway, N. Y.

Bickford, Nathan B.
61 Minot Street, Neponset, Mass.

Bigelow, James F.
City Engineer, Marlboro, Mass.

Billings, William R.
15 Harrison Street, Taunton, Mass.

Birkinbine, Henry.
General Manager Water and Gas Company, York, Pa.

Bisbee, Forrest E.
Superintendent, Auburn, Me.

Bishop, George H.
Civil Engineer, Middletown, Conn.

Bishop, Watson L.
Superintendent, Dartmouth, N. S.

Blackmer, James W., 2d.
Superintendent, Beverly, Mass.

Bliss, Gerald M.
Civil Engineer, 19 Cottage Street, Providence, R. I.

Blossom, William L.
Civil Engineer, 355 Washington Street, Brookline, Mass.

Boggs, Edward M.
Civil Engineer, 535 Stinson Block, Los Angeles, Cal.

Bowers, George.
City Engineer, Lowell, Mass.

Bracket, Dexter.
Engineer Distribution Dept., Metropolitan Water Board, 3 Mt. Vernon Street, Boston, Mass.

Bradley, R. H.
Superintendent, Le Sueur, Minn.

Brinsmade, Daniel S.
Engineer and Agent, Ousatonic Water Co., Birmingham, Ct.

Broatch, J. C.
Superintendent, Middletown, Conn.

Brooks, E. C.
Superintendent, Cambridge, Mass.

Brooks, Fred.
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Registrar, Fitchburg, Mass.

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Brown, J. Henry.
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Brown, Walter I.
Registrar, Bangor, Me.

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Bryant, C. B.
City Engineer, Martinville, Va.

Buckman, George A. P.
Superintendent, Norwood, Mass.

Burke, James E.
Superintendent Princeton Water Co., Princeton, N. J.

Burleigh, John M.
Superintendent, South Berwick, Me.

Burley, Harry B.
31 Milk Street, Room 55, Boston, Mass.

Burnham, Albert S.
Superintendent, Revere, Mass.

Burnie, James.
Superintendent, Biddeford, Me.

Burr, William H.
Professor of Civil Engineering, Columbia College, and Consulting Engineer, New York City.

Burse, A. H.
Superintendent, Pittsfield, Me.

Bush, Edward W.
171 Ashley Street, Hartford, Conn.

Butler, J. Allen.
Superintendent, Portland, Conn.

Cairns, R. A.
City Engineer, Waterbury, Conn.

Card, Huber D.
City Engineer, Willimantic, Conn.

Carroll, Fred B.
8 Dexter Street, Woonsocket, R. I.

Cassell, George.
Superintendent Water Works, Chelsea, Mass.

Caulfield, John.
Secretary Water Works, St. Paul, Minn.

Cavanagh, John T.
Commissioner Public Works Quincy, Mass.

Chace, George F.
Superintendent, Taunton, Mass.

Chadbourne, E. J.
Superintendent, Wakefield, Mass.

Chandler, Charles E.
City Engineer, 161 Main Street, Norwich, Conn.

Chandler, Charles F.
Professor of Chemistry School of Mines, Columbia College, New York City.

Chandler, Henry.
Water Commissioner, Manchester, N. H.

Chapin, G. L.
Water Commissioner, Lincoln, Mass.

Chapman, Benjamin R.
~~City~~ Engineer, Brockton, Mass.

Chase, John C.
Chief Engineer Water Works, Wilmington, N. C. Address, Derry, N. H.

Clapton, William.
Superintendent, Newtown, N. Y.

Clark, A. D.
Secretary Spring Water Co., Kane, Pa.

Clark, D. W.
President Water Co., Portland, Me.

Clark, Frederic.
Water Commissioner, North Billerica, Mass.

Clark, Frederick W.
Clerk Chestnut Hill Reservoir, Boston Water Works, Brighton, Mass.

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Sewer Commissioner, Brockton, Mass.

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Superintendent, Nahant, Mass.

Codd, William F.
Superintendent, Nantucket, Mass.

Coffin, Freeman C.
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Coggeshall, R. C. P.
Superintendent, New Bedford, Mass.

Cole, F. M.
Inspector, Brockton, Mass.

Collins, Lewis P.
Water Commissioner, Lawrence, Mass.

Colson, Charles D.
Water Commissioner, Holyoke, Mass.

Conant, H. W.
Superintendent, Gardner, Mass.

Conant, Whitney.
Secretary Water Co., Long Branch, N. J.

Connell, Michael A.
Superintendent, St. Hyacinthe, P. Q.

Cook, Byron I.
Superintendent, Woonsocket, R. I.

Cook, Henry A.
Superintendent, Salem, Mass.

Cram, Arthur N.
Water Commissioner, Walpole, Mass.

Crandall, F. H.
Superintendent and Treasurer, Burlington, Vt.

Crandall, George K.
Civil Engineer, New London, Conn.

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Clerk Water Board, Lowell, Mass.

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Davis, F. A. W.
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Davis, Henry L.
Superintendent, Wallingford, Conn.

Davis, J. M.
Rutland, Vt.

Davis, William E.
Superintendent, Sherburne, N. Y.

Davison, George S.
Civil Engineer, Pittsburg, Penn.

Dawson, Alex. S.
Civil Engineer Canadian Pacific Railway, Winnipeg, Manitoba, Canada.

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Dean, Seth.
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Dean, William H.
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Denman, A. N.
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Dennett, Nathaniel.
Superintendent of Construction, Somerville, Mass.

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Diven, J. M.
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Doran, Hugh F.
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Dotten, William T.
Superintendent, Winchester, Mass.

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Drake, B. Frank.
Water Commissioner, Lakeport, N. H.

Drake, Charles E.
Civil Engineer, New Bedford, Mass.

Drown, Thomas M.
President Lehigh University, South Bethlehem, Penn.

Dunbar, E. L.
Superintendent, Bay City, Mich.

Dyer, Eben R.
Superintendent of Distribution, Portland, Me.

Eardley, B. A.
Superintendent Pacific Improvement Co. Water Works, Pacific Grove, Monterey County, Cal.

Eastman, Henry E.
Superintendent, Westport, N. Y.

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Ellis, John W.
Civil Engineer, Woonsocket, R. I.

Ellsworth, Emory A.
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Secretary and Treasurer Middleton Water Supply Co., Bridgeton, N. S.

Esterbrook, Arthur F.
Water Commissioner, Leicester, Mass.

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Ewell, William Walter.
Quincy, Mass.

Fairbanks, J. H.
Chairman Water Commissioners, Winchendon, Mass.

Fales, Frank L.
Assistant Engineer, Engineering Dept., Board of Trustees, Commissioners Water Works, Cincinnati, O.

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Fifield, John W. D.
Water Commissioner, North Brookfield, Mass.

Fish, J. B.
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Fitch, Jasper A.
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Fitzgerald, Desmond.
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Professor of Sanitary and Hydraulic Engineering, Lafayette College, Easton, Penn.

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Forbes, F. F.
Superintendent, Brookline, Mass.

Forbes, Murray.
Manager Westmorland Water Co., Greensburgh, Penn

Forbes, Z. R.
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President Factory Insurance Cos., Providence, R. I.

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Fuller, George W.
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Gamwell, J. H.
Treasurer Water Company, Palmer, Mass.

Gardner, L. H.
Superintendent Water Works Company, New Orleans, La.

Gear, A. S.
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Geer, Harvey M.
Civil Engineer, Ballston Spa, N. Y.

Gerhard, William Paul.
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Superintendent and Engineer, Oberlin, Ohio.

Gerry, L. L.
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Gilbert, Julius C.
Superintendent, Whitman, Mass.

Gilderson, D. H.
Superintendent, Haverhill, Mass.

Gleason, Fred B.
Inspector, Marlboro, Mass.

Gleason, J. F.
Foreman, Quincy, Mass.

Gleason, T. C.
Superintendent, Ware, Mass.

Glover, Albert S.
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Goldthwait, W. J.
Marblehead, Mass.

Goodnough, X. H.
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Gould, Amos A.
Water Commissioner, Leicester, Mass.

Gould, J. A.
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Superintendent, Medford, Mass.

Gowing, E. H.
95 Milk Street, Boston, Mass.

Graham, James W.
Superintendent, Meter Department, Portland, Me.

Greaney, Thomas F.
Water Commissioner, Holyoke, Mass.

Greene, S. C.
Chairman Water Board, St. Albans, Vt.

Greetham, H. W.
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Griffith, William E.
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Groce, William R.
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Gubelman, F. J.
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Waterville, Me.

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Hancock, Joseph C.
Superintendent, Springfield, Mass.

Hardy, J. D.
Superintendent, Holyoke, Mass.

Haring, James S.
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Harrington, George W.
Wakefield, Mass.

Harris, D. A.
Superintendent, New Britain, Conn.

Hart, Edward W.
General Manager Water Works, Council Bluffs, Iowa.

Hartwell, David A.
City Engineer, Fitchburg, Mass.

Haskell, John C.
Superintendent, Lynn, Mass.

Hastings, L. M.
City Engineer, Cambridge, Mass.

Hastings, V. C.
Superintendent, Concord, N. H.

Hatch, Arthur Elliot.
Mechanical Engineer, Bay State Dredging Co., 59 High Street, Boston, Mass.

Hatch, S. S.
Water Commissioner, South Norwalk, Conn.

Hathaway, A. R.
Registrar, Springfield, Mass.

Hathaway, James H.
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Hawes, George Mason.
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Hawes, Louis E.
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Hawes, William B.
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Heermans, Harry C.
Superintendent, Corning, N. Y.

Henderson, Wilson.
Superintendent, Peterborough, Ontario, Canada.

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Herschel, Clemens.
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Hill, Hibbert Winslow.
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Hodgdon, Frank W.
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Hodgson, John S.
Wellington, Mass.

Holden, Andrew.
Water Commissioner, Fall River, Mass.

Holden, Horace G.
Superintendent, Nashua, N. H.

Hollis, Frederic S.
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Holman, M. L.
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Hopkins, Charles C.
Stanwix Engineering Company, Rome, N. Y.

Hubbell, Clarence W.
Water Office, Detroit, Mich.

Hunking, Arthur W.
Care Mass. Mills, Lindale, Floyd County, Georgia.

Hunter, Henry G.
Civil Engineer, Quincy, Mass.

Huntington, James A.
Registrar, Haverhill, Mass.

Hyde, Horatio N.
Newtonville, Mass.

Jackson, Daniel D.
Chemist Division of Water Supply, Mt. Prospect Laboratory, Brooklyn, N. Y.

Jackson, William.
City Engineer, City Hall, Boston, Mass.

Johnson, H. R.
Water Commissioner, Reading, Mass.

Johnson, William S.
Assistant Engineer State Board of Health, Room 140, State House, Boston, Mass.

Jones, A. J.
New Brunswick, N. J.

Jones, James A.
Registrar, Stoneham, Mass.

Jones, R. A.
Civil Engineer, Spokane, Washington.

Jordan, John N.
Superintendent, Malden, Mass.

Judkins, Fred G.
Franklin Falls, N. H.

Junkins, George S.
Water Commissioner, Lawrence, Mass.

Keating, E. H.
Manager Toronto Railway Co., Toronto, Ontario, Canada.

Kent, E. W.
Civil Engineer, Woonsocket, R. I.

Kent, Willard.
Manager Water Company, Narragansett Pier, R. I.

Kieran, Patrick.
Superintendent, Fall River, Mass.

Kimball, Frank C.
Superintendent Knoxville Water Co., 608 South Gay Street, Knoxville, Tenn.

Kimball, George A.
Member Metropolitan Sewerage Board, Room 1102, Exchange Building, 53 State Street, Boston, Mass.

Kingman, Horace.
Superintendent, Brockton, Mass.

Kinnicut, Leonard P.
77 Elm Street, Worcester, Mass.

Kinsey, Warren R.
Civil Engineer, 108 Fulton Street, New York City.

Knapp, Louis H.
Engineer Buffalo Water Works, 280 Linwood Avenue, Buffalo, N. Y.

Knight, Charles William.
Stanwix Engineering Company, Rome, N. Y.

Knowles, Morris.
Room 780 City Hall, Philadelphia, Pa.

Koch, Harry G.
Superintendent Castle Creek Water Company, Aspen, Colorado.

Kuehn, Jacob L.
Superintendent, York, Penn.

Kuichling, Emil.
Chief Engineer Water Works, Rochester, N. Y.

Laforest, J. O. Alfred.
Superintendent, Montreal, Quebec.

Laing, W. H.
Secretary and Superintendent, Racine, Wis.

Landon, H. C.
Civil Engineer, 728 East Capitol Avenue, Springfield, Ill.

Lansing, Edward T. E.
Civil Engineer, Little Falls, N. Y.

Lautz, Adolphe W.
Secretary Water Company, Pekin, Ill.

Lawton, Perry.
Civil Engineer, Savings Bank Building, Quincy, Mass.

Lea, R. S.
Assistant Professor of Civil Engineering, McGill University, Montreal, P. Q.

Learned, Wilbur F.
Civil Engineer, Watertown, Mass.

Linsley, J. H.
196 Main Street, Burlington, Vt.

Locke, James W.
Foreman, Brockton, Mass.

Lord, Harry A.
Superintendent, Ogdensburg, N. Y.

Loretz, Arthur J. L.
Mechanical Engineer, 126 Liberty Street, New York City.

Lovell, Thomas C.
Superintendent. Office, 104 River Street, Fitchburg, Mass.

Luce, Francis H.
Superintendent, Woodshaven, N. Y.

Lunt, Cyrus M.
Superintendent, Lewiston, Me.

Lusk, James L.
Captain Corps of Engineers, U. S. A., in charge of water supply, U. S. Military Academy, West Point, N. Y.

Luther, William J.
Superintendent and Registrar, Attleboro, Mass.

MacMurray, John C.
President Cherryvale Water Company, Cherryvale, Kan. Address, 33 Oak Avenue, Worcester, Mass.

Mann, Thomas W.
Civil Engineer, Holyoke, Mass.

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